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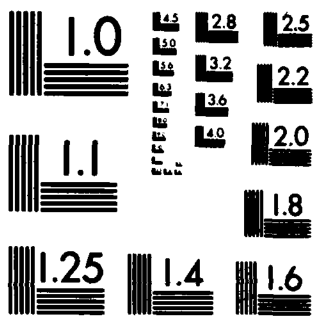
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RADC-TR-83-56
Final Technical Report
March 1983

MODIFICATIONS TO ACOSS MODEL #2 DESIGN

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The Charles Stark Draper Laboratory, Inc.

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MODIFICATIONS TO ACOSS MODEL #2 DESIGN

Timothy Henderson

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An updated version of the Active Control of Space Structure (ACOSS) Evaluation Model, ACOSS Model #2, has been designed and analyzed. This updated model reflects the need for closer correlation between model performance and actual system performance at the cost of increased model complexity. Using this updated model, two additional models have been created to fulfill the needs of the VCOSS program. The first VCOSS model is a minimum mass, flexible design. A vibration control system including hardware

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specifications will be designed for this model. This design will be compared with that based on the second VCOSS model. This model is a maximum mass, stiffness controlled design. The purpose of this design is to reduce control system requirements by stiffening the structure in order to raise critical modal frequencies. The MSC/NASTRAM finite element models for all three designs are listed in the Appendices.

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SECTION 1

INTRODUCTION

In recent years the development of the technology for active control of structural vibrations of Large Space Stuctures (LSS) has been addressed in the Active Control of Space Structures (ACOSS) program. Early in the program a need for a common design model to allow evaluation and comparison of the various approaches was identified. The first design model, ACOSS Model 1, was developed in 1979. This structure, a simple ground attached tetrahedron, provided a means of evaluating control designs but lacked any real physical relationship with typical LSS. Because of the desire for an evaluation model which had dimensions, materials, optical system, and performance more closely related to actual structures, ACOSS Model #2 was developed in May 1980. In order to meet the design goal of a low-order structural model, many simplifying assumptions were made in the modelling of the optical system mirrors and the supporting structure. This was consistent with the desire to use the model to evaluate control design methods without concern for detailed mechanical design of the components. This model has provided a simple means of comparing and evaluating the control designs of the various ACOSS contractors. A complete description of the model along with a set of disturbances is contained in Reference 1.

The Vibration Control of Space Structures (VCOSS) program is intended to study the application of ACOSS technology to an actual spacecraft design. This includes specification of sensor and actuator hardware and assessment of the performance of the system including these components. The system model will be based on ACOSS Model #2, but with modifications to reduce the structural mass to the minimum required to maintain structural stability. This system will rely entirely upon the control system for vibration suppression to meet the performance requirements. This will be compared with another model which is also a modification of ACOSS Model #2. This second design will be a strengthened version of Model #2. The goal of this design is to meet the performance specifications by passive means: structural stiffening and passive damping. The structure will be stiffened by increasing the sizes of the existing members in Model #2 until the total system mass is equal to the maximum cargo capacity of the shuttle into polar orbit, 15000 kg. No additional structural members will be added so that the only difference between the two designs will be the size of the members.

The first step in modifying ACOSS Model #2 to generate the two models required for the VCOSS program was to reassess the basic assumptions which were used in the design. This is necessary because in order to establish the hardware requirements of a vibration control system the system model must accurately reflect the mechanical properties of an actual system. In this structure the important properties are the interaction of the rigid mirrors with the flexible support and the interface

between the equipment section and the optical support truss. In the original design of ACOSS Model #2, the goal of minimizing the total number of degrees-of-freedom in the system resulted in a simple method of including the mirror mass effects. This approach did not include details of the kinematic connection of the mirrors to the structure or of the motion of the mirror centroids. The modelling of the equipment section did not provide adequate space for the isolation system which will separate the two bodies.

Section 2 describes an updated version of ACOSS Model #2. This update reflects the need for a more detailed model which more closely reflects the behavior of an actual spacecraft and can be used as a basis for the hardware implementation studies required in the VCOSS program. In this updated design the original geometry and stiffness are retained as much as possible. Changes were made to the structural model to include the rigid body inertia properties of each mirror and a detailed kinematic mount connecting it to the support structure. In addition, the model of the equipment section was changed to include a more representative mass distribution and to provide clearance for the isolation system hardware.

Using this updated design as a baseline, the two VCOSS models were generated. Section 3 describes the minimum mass, strength-controlled design. In this model, the size of each structural member has been reduced to the minimum allowed by constraints on local buckling, member natural frequency and minimum wall thickness for the tube sections. The updated finite element model and natural frequency tables are listed.

The stiffness-controlled design is described in Section 4. Each structural member has been increased in order to uniformly increase the stiffness of the structure. A limit of 15000 kg has been placed on the total mass of the system to allow for placement into a polar orbit by the shuttle. The updated finite element model and natural frequency tables are given.

In order to avoid confusion between the original ACOSS Model #2 and the three new versions of it which are described in this report, a system of revision numbers has been established. This will provide a means of easily identifying the existing versions as well as all those which may be generated in the future.

Revision 0: The original ACOSS Model #2, first presented in May 1980.

Revision 1: Updated version of the original design which includes more detailed mirror and equipment section modes. This design is described in Section 2.

Revision 3: The strength controlled, minimum mass design based on Revision 1. This is the VCOSS actively controlled design. Details of the model are presented in Section 3.

Revision 4: The stiffness controlled maximum mass design based on Revision 1. This design is presented in Section 4.

<u>Reference 1</u>

RADC-TR-80-377, Interim Report, Jan 1981, "ACOSS Six (Active Control of Space Structures)

SECTION 2

UPDATED STRUCTURAL DESIGN

2.1 Introduction

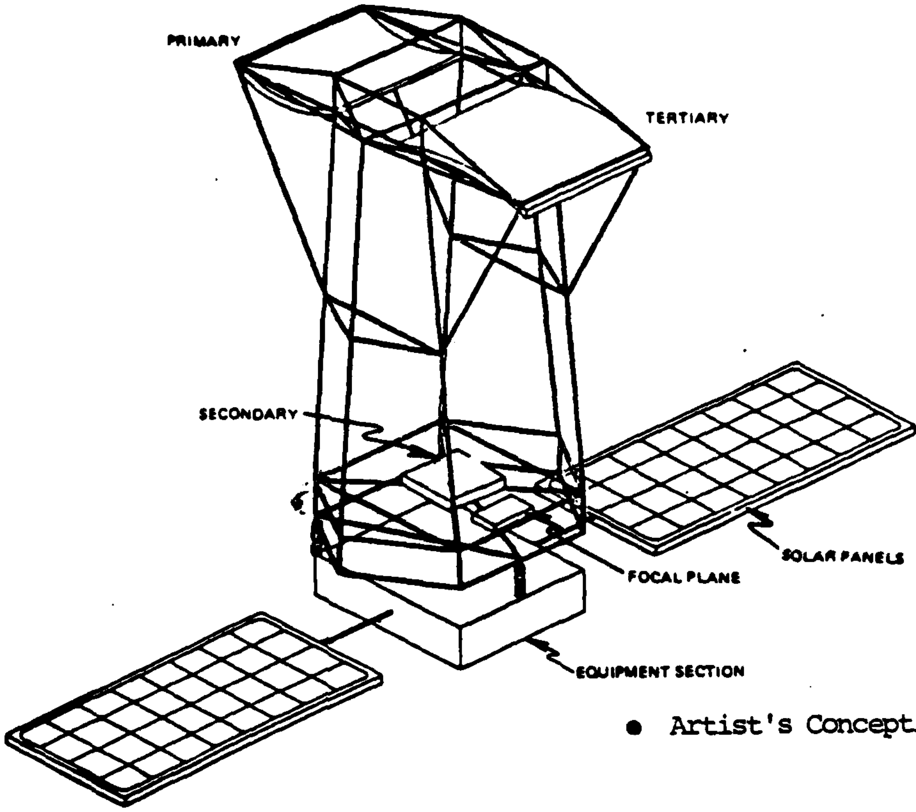
The baseline design for the two VCOSS models is the original ACOSS Model #2 shown in Figure 2.1. This model was generated in May 1980 to provide a simple, unclassified tool to evaluate the active control philosophies proposed by a variety of sources. As the needs of the users of the model have changed, the model has been changed to provide the required fidelity. An updated ACOSS Model #2 is presented in this section. Stiffness controlled and strength controlled versions of this updated model will be described in following chapters. The design changes which were incorporated into this update reflect the need to provide better correlation between this simplified model and typical large space structures.

The changes which were made to Model #2 are confined to two areas, the details of the mirror support structures and the equipment section. The metering truss, which separates the upper and lower mirrors, the solar panels, and the isolation springs are unchanged from the original design. The modifications to the structural design and the finite element model are described in the following sections. The NASTRAN input data for this model is listed in Appendix A. The finite element model for Revision 1 is shown in Figure 2.2.

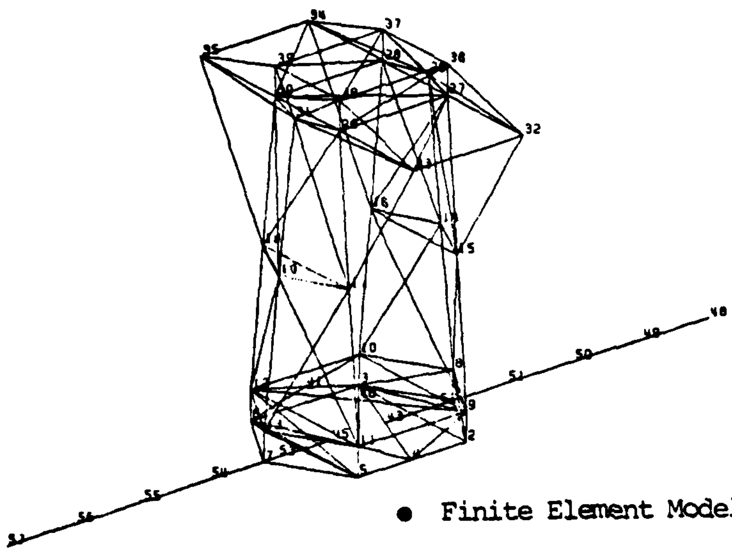
In order to facilitate these modifications and the structural modifications in the VCOSS designs, the structural and non-structural mass have been uncoupled. In Revison 0, the structural mass was added to the non-structural mass and lumped at the mirror support points. In the new model, the non-structural mass is lumped at the mirror centroids and support points and the structural mass is lumped at all node points. The structural mass will be computed automatically by NASTRAN using the length and area of each member and the material density of 1720 kg/m^3. The structural and non-structural mass at each node point and the system mass properties for Revision 1 are listed in Table 2.1.

2.2 Mirror Design Modifications

Modifications were made to the models of the mirrors in the system in order to reflect, in detail, the interaction between the rigid mirrors and the flexible optical support truss. In the original design, (Revision 0), in which the number of lumped masses was kept to a minimum, it was assumed that the masses of each mirror and its supporting structure were evenly distr' uted to t' s support points without regard to the detail of the connecti.



• Artist's Conception



• Finite Element Model

Figure 2.1. ACOSS Model #2 (Revision 0)

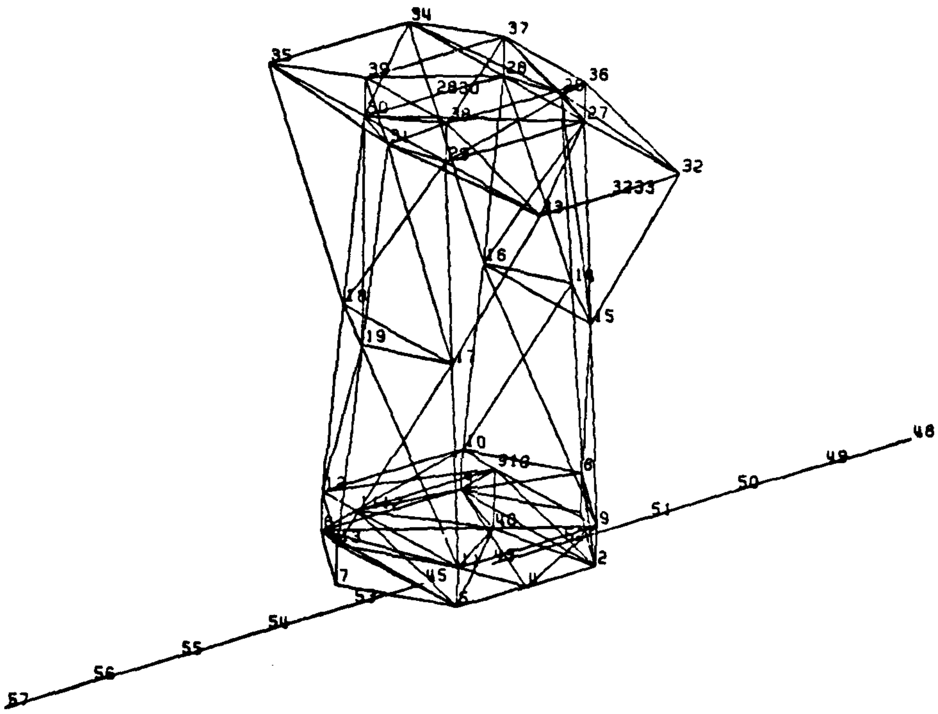


Figure 2.2: ACOSS Model #2 (Revision 1)

Table 2.1. Lumped mass distribution

node	structural mass (kg)	non-struct. mass (kg)	node	structural mass (kg)	non-struct. mass (kg)
1	7.34		36	9.99	
2	21.97		37	12.17	
3	34.03		38	12.17	
4	20.86		39	9.99	
5	21.97		40	26.85	
6	33.83		42	0.0	
7	7.34		43	3.24	
8	21.13		44	0.0	3500.
9	25.40	67.4	45	3.24	
10	21.50	67.4	46	0.0	
11	25.40	67.4	47	0.0	
12	21.57	67.4	48	4.05	81.91
13	21.13		49	8.09	
14	16.59		50	8.09	163.82
15	21.48		51	8.09	
16	22.71		52	7.28	73.82
17	21.48		53	7.28	73.82
18	22.71		54	8.09	
19	16.59		55	8.09	163.82
26	17.53		56	8.09	
27	23.00	69.50	57	4.05	81.91
28	45.94	6.74	910	23.51	
29	17.25	69.50	1001		1000.0
30	51.70	6.74	1002		800.0
31	17.53		1003		1200.0
32	43.51	6.74	1004		600.0
33	47.09	6.74	1112	23.64	
34	18.41	69.50	2330	62.76	
35	14.83	69.50	3233	62.76	
Totals				1023.34	8313.66

Total mass = 9337 kg

Center of Mass Location

x = 0.0 m

y = -0.237 m

z = 6.933 m

The new mirror models assume that each surface is a planar rigid body which is connected to the support structure by kinematic mounts. This type of mount can only transmit rigid body motion between the support structure and the mirror. Elastic motion of the support points relative to each other will not cause any deformation of the mirror surface. The finite element model has been changed so that the translational and rotational inertia properties of each mirror are lumped at a node point at its center of mass. This node is connected to the three support points of the surface by rigid elements which are attached at the six degrees of freedom required for the kinematic mount. The details of a kinematic mount are shown in Figure 2.3. In the drawing, point A is supported in the x, y, and z directions, point B is supported in the y and z directions, and point C is supported in the z direction.

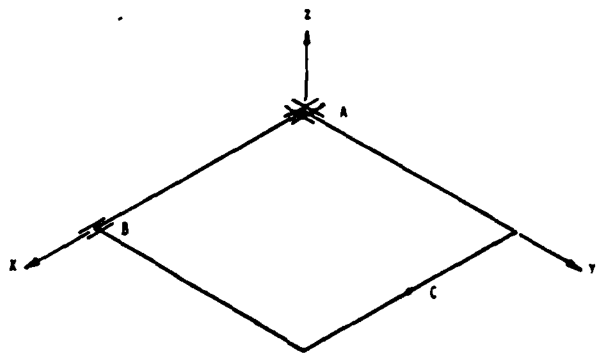


Figure 2.3: Typical kinematic mount

The new model of each mirror will be described in the following sections. A summary of these models is given in Table 2.2.

2.2.1 Primary Mirror

The primary mirror is one of the two large mirrors at the top level of the optical support truss. In the original design (Revision 0) masses were lumped at nodes 34, 35, 28, and 30 to represent the structural and non-structural mass associated with this surface. The motion of the mirror was defined by a kinematic mount with point A at 34, point B at node 35, and point C located midway between nodes 28 and 30. The displacement at point C was interpolated from the two nodal values. This kinematic mount was not included in the finite element model but was used only in the line-of-sight error model.

In the new design, two new node points are added to the finite element model. One, node 1001, is located at the center of mass. The second, node 2830, lies midway between nodes 28 and 30 to provide the third

support point for the kinematic mount. The beam element connecting nodes 28 and 30 and containing node 2830 has been strengthened to support the mass of the mirror. The stiffened beam is a tubular truss as shown in Figure 2.4. It is designed to prevent significant line-of-sight errors due to bending at frequencies below 40 Hz. The center of mass is connected to the support points by rigid elements which are constrained in the six degrees of freedom required for the kinematic mount. The new model of the primary mirror is shown in Figure 2.5.

2.2.2 Secondary Mirror

The motion of the secondary mirror was defined in Revision 0 by the six degrees of freedom (three translations and three rotations) at node 40. The mass was lumped at the edge nodes of the lower support truss so that the motion of the mirror plane was equal to the motion of node 40. In the new model, the mass of the secondary will be lumped at its center of mass, node 1002, which will be attached to the supporting structure by a kinematic mount as shown in Figure 2.6. The structural design was altered to include the additional support points for the secondary. The finite element model was changed by adding the two support point nodes, node 910 and node 1112, moving node 40, and including the members required to brace the supports. Point A of the mount will be node 910, point B will be node 1112, and point C will be node 40. Rigid bars provide the connection between the mount degrees of freedom and the center of mass.

2.2.3 Tertiary Mirror

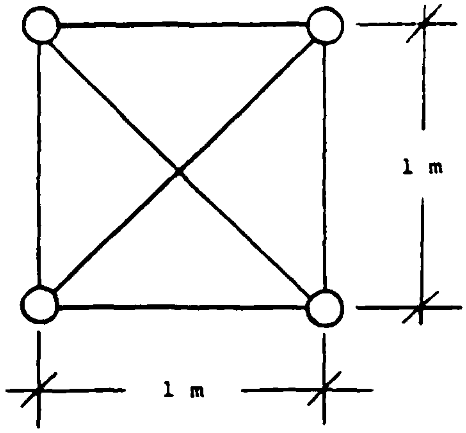
The changes in the model of the tertiary mirror are similar to those made in the model of the primary. The center of mass is located at node 1003. It is kinematically mounted on the support truss by connections to node 27 (point A), node 29 (point B), and node 3233 (point C). Node 3233 is located midway between nodes 32 and 33 on the stiffened beam connecting them. The new configuration of the tertiary mirror model is shown in Figure 2.5.

2.2.4 Focal Plane

The only change made to the model of the focal plane consists of the addition of the kinematic mount. The mass properties of the focal plane are lumped at its center of mass, node 1004. Rigid bars connect it to the three support points, node 11 (point A), node 9 (point B), and node 40 (point C). The new configuration is shown in Figure 2.6.

Table 2.2. Modified Mirror Models

Primary:		
	Mass = 1000 kg	Center of Mass: node 1001
	$I_{xx} = 4083.33\ kg\text{-}m^2$	Support Points:
	$I_{yy} = 5333.33\ kg\text{-}m^2$	Node 34 dof 1,2,3
		Node 35 dof 2,3
	$I_{zz} = 9416.67\ kg\text{-}m^2$	Node 2830 dof 3
Secondary:		
	Mass = 800 kg	Center of Mass: node 1002
	$I_{xx} = 1666.67\ kg\text{-}m^2$	Support Points:
	$I_{yy} = 4266.67\ kg\text{-}m^2$	Node 910 dof 1,2,3
		Node 1112 dof 2,3
	$I_{zz} = 5933.33\ kg\text{-}m^2$	Node 40 dof 3
Tertiary:		
	Mass = 1200 kg	Center of Mass: node 1003
	$I_{xx} = 4900.00\ kg\text{-}m^2$	Support Points:
	$I_{yy} = 6400.00\ kg\text{-}m^2$	Node 27 dof 1,2,3
		Node 29 dof 2,3
	$I_{zz} = 11300.0\ kg\text{-}m^2$	Node 3233 dof 3
Focal Plane:		
	Mass = 600 kg	Center of Mass: node 1004
	$I_{xx} = 200.00\ kg\text{-}m^2$	Support Points:
	$I_{yy} = 800.00\ kg\text{-}m^2$	Node 11 dof 1,2,3
		Node 9 dof 2,3
	$I_{zz} = 1000.00\ kg\text{-}m^2$	Node 40 dof 3



Tube Properties:

Radius = 0.11 m

t = 0.0022 m

Area = 0.00152 m^2

Section Properties:

Area = 4 A_{tube} = 0.00608 m^2

I = 0.00152 m^4

J = 0.00304 m^4

Mass/L = 15.69 kg/m

Figure 2.4. Stiffened mirror support beam

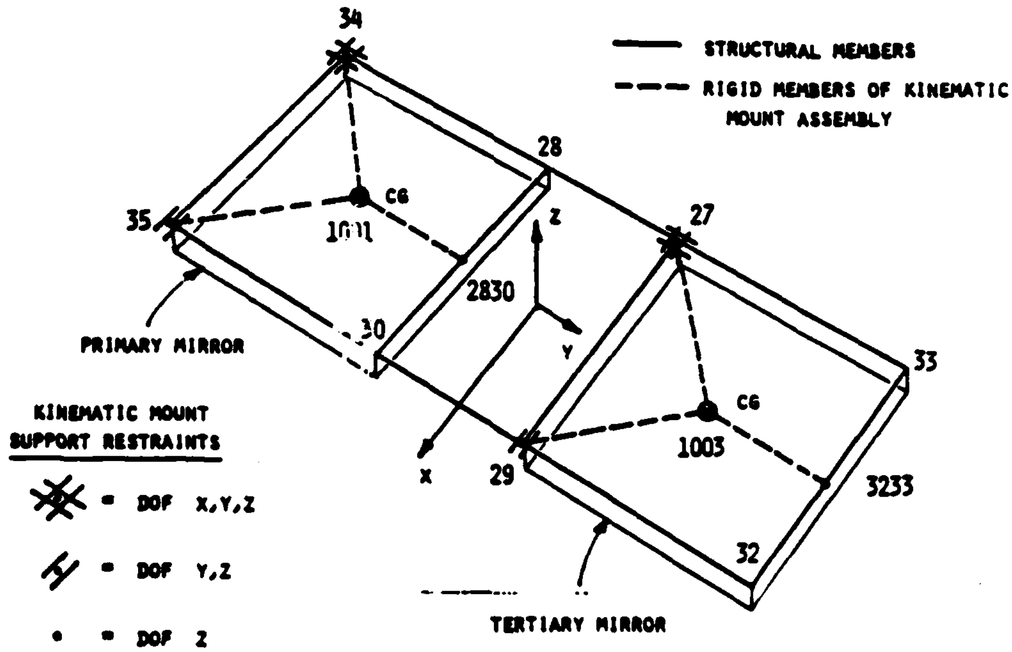


Figure 2.5. Modified primary and tertiary mirror models

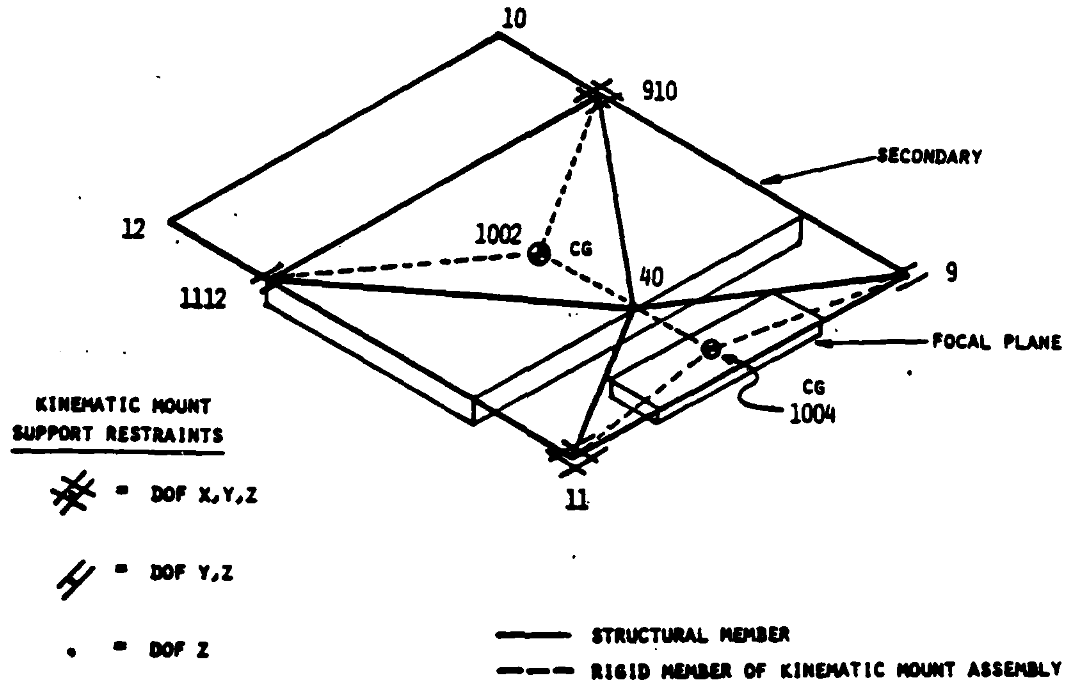


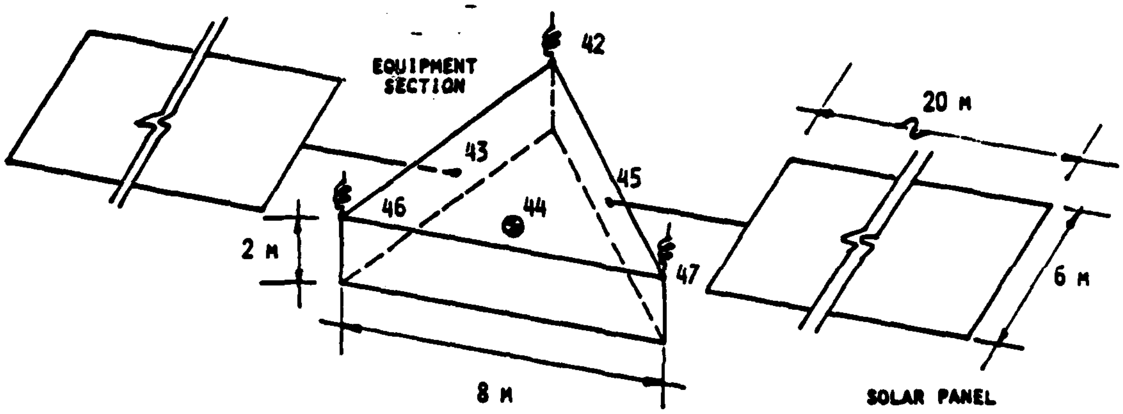
Figure 2.6. Modified secondary and focal plane mirror models

2.3 EQUIPMENT SECTION MODIFICATIONS

Changes were also made to the model of the equipment section. In the original design the equipment section was modelled as a rigid plate and located at the same point on the z-axis as the lower chord of the optical support truss. The two sections were connected by springs as part of the isolation system. While this configuration is mathematically correct, in an actual system the springs will have a finite length. The equipment section will now be modelled as a uniform rigid body, triangular in shape and two meters in depth. The equipment section and the optical support truss will be separated by thirty centimeters to allow room for the isolation system. The new mass properties and location of the equipment section are given in Figure 2.7.

2.4 LINE-OF-SIGHT-ERROR MODEL CHANGES

Due to changes in the models of the mirrors and their support points, a few minor changes are necessary in the implementation of the line-of-sight error model for Revision 1 and all later versions. This



- EQUIPMENT SECTION MODELLED AS RIGID BODY

Mass = 3500 kg

I_{xx} = 20611.11 kg-m^2

I_{yy} = 10500.00 kg-m^2

I_{zz} = 28777.77 kg-m^2

Center of Mass (node 44)

x = 0.0 m

y = -1.67 m

z = -1.30 m

Figure 2.7. Equipment section properties

error model relates the rotation about the x and y axes and the defocus of the line-of-sight to the displacements of the mirror support point nodes in the finite element model. Full details about the theory and implementation of the error model are given in CSDL Report C-5437. The changes in the updated version are due to the addition of the nodes 2830 and 3233 in the kinematic mount models for the primary and tertiary mirrors and the addition of the kinematic mount for the support of the secondary. The updated equations relating LOS errors to node point displacements are:

$$\begin{aligned}
\text{LOSX} = & -(.0186)Y_{34} - (.1429)Z_{34} - (.0186)Y_{35} - (.1429)Z_{35} \\
& + (.2857)Z_{2830} + (.0807)Y_{27} - (.3549)Z_{27} + (.0807)Y_{29} \\
& - (.3549)Z_{29} + (.7098)Z_{3233} - (3.4842)\theta X_{1002} - (.0621)Y_{11} \\
& - (.0621)Y_{9}
\end{aligned}$$

$$\begin{aligned}
\text{LOSY} = & -(.0371)X_{34} - (.0464)Y_{34} - (.2500)Z_{34} + (.0464)Y_{34} \\
& + (.2500)Z_{35} + (.1613)X_{27} - (.0605)Y_{27} - (.6211)Z_{27} \\
& + (.0605)Y_{29} + (.6211)Z_{29} + (3.4842)\theta y_{1002} - (.1242)X_{11} \\
& - (.0776)Y_{11} + (.0776)Y_{9}
\end{aligned}$$

$$\begin{aligned}
\text{DEFOCUS} = & -(.0191)Z_{34} - (.0191)Z_{35} + (.1274)_{2830} \\
& + (.7780)Z_{27} + (.7780)Z_{29} - (.4668)Z_{3233} - (2.000)Z_{40} \\
& - (.1785)Z_{1002} + (.5000)Z_{9} + (.5000)Z_{11}
\end{aligned}$$

Since this model is a linear function of the nodal displacements it is included as a set of constraint equations in the NASTRAN finite element model. The three line-of-sight components are assigned to an added node which is not part of the structural model. In all revisions of ACOSS Model #2 the line-of-sight errors are included at node 100 so that:

node 100 dof 1 = losx

node 100 dof 2 = losy

node 100 dof 3 = defocus

2.5 ANALYSIS

A normal modes analysis of the finite element model containing all of the changes, Revision 1, was performed using the MSC/NASTRAN finite element program. The resulting frequencies are shown in Table 2.3. Also listed in the table are the components of the line-of-sight errors for each mode, node 100. These are based on modes which have been normalized to a unit generalized mass.

Table 2.3. ACOSS Model #2: Revision 1

NODE	FREQ(HZ)	LOSX	LOSY	DEFOCUS
1	0.0	-.8878E-14	-.1153E-09	-.6815E-16
2	0.0	-.1002E-08	-.1652E-13	-.1854E-15
3	0.0	-.1595E-07	-.9235E-08	-.1712E-08
4	0.0	0.9146E-03	-.7006E-08	0.1018E-08
5	0.0	0.1445E-06	-.8877E-03	0.4225E-11
6	0.0	0.1259E-07	-.6264E-04	0.2997E-12
7	0.148	0.2944E-07	-.3898E-03	0.4991E-06
8	0.282	0.1019E-05	0.1605E-03	0.2903E-06
9	0.319	-.2994E-04	-.2654E-06	0.3597E-05
10	0.335	-.2318E-03	0.6658E-09	-.1997E-05
11	0.468	-.3502E-05	-.7817E-06	0.1190E-04
12	0.583	0.8321E-03	0.6739E-06	0.2198E-04
13	0.601	0.2635E-05	-.7260E-03	0.4251E-05
14	0.673	-.4559E-04	0.8519E-06	-.9385E-05
15	0.960	0.3227E-05	0.1137E-03	0.1875E-05
16	1.092	-.6245E-06	0.2142E-03	0.7325E-06
17	1.839	-.1215E-04	-.1146E-06	-.2534E-05
18	1.844	0.1361E-05	-.2285E-06	0.2419E-05
19	1.889	0.1181E-13	0.5645E-15	0.3941E-17
20	1.990	-.1223E-04	-.5338E-06	0.2071E-05
21	2.060	0.5702E-05	0.3210E-03	0.3580E-05
22	2.452	-.3870E-04	-.2272E-02	-.2578E-04
23	2.472	0.3831E-04	0.3097E-02	0.3108E-04
24	3.242	0.3480E-05	-.1982E-01	-.1460E-03
25	5.162	-.1299E-13	-.4795E-15	-.5870E-18
26	5.170	0.2129E-05	0.2360E-07	-.6659E-07
27	7.877	-.5425E-13	0.3615E-15	-.2031E-17
28	7.918	-.6648E-05	-.4719E-07	-.2121E-05
29	8.772	-.3142E-02	-.8166E-05	-.2629E-02
30	8.776	0.2061E-01	0.5367E-04	0.1725E-01
31	8.838	-.1379E-03	-.2637E-06	-.1199E-03
32	8.980	-.1254E-05	0.4521E-05	-.1074E-05
33	9.620	0.1002E-06	0.3876E-04	0.7744E-06
34	10.395	0.2826E-04	-.6607E-02	0.7576E-03
35	11.673	-.1582E-02	0.7234E-03	0.2424E-01
36	12.266	-.1564E-03	0.6938E-03	0.1362E-02
37	13.387	-.1267E-01	0.2097E-02	-.6898E-01
38	13.616	0.3277E-02	0.1034E-01	0.1220E-01
39	14.771	0.2091E-01	0.1710E-03	0.1023E-01
40	16.432	0.1461E-02	-.1737E-01	-.5131E-03
41	20.832	0.6769E-03	0.4698E-02	-.2820E-02
42	21.792	-.2018E-01	0.2340E-02	-.2074E-01
43	21.845	0.1289E-05	-.9632E-07	0.5591E-06
44	21.849	0.2475E-04	-.2563E-05	0.3027E-04
45	21.849	-.2202E-05	-.1995E-05	-.2268E-05
46	21.880	0.2317E-05	0.4840E-05	0.2596E-05
47	23.755	-.1275E-02	-.3947E-01	-.1180E-01
48	24.472	0.3467E-02	0.4696E-02	-.6944E-01
49	24.941	-.1052E-01	-.1291E-01	0.7234E-01
50	25.876	0.3684E-02	-.4148E-01	-.2241E-01
51	26.489	0.4406E-12	0.4621E-11	0.9003E-11
52	27.978	0.8897E-02	0.4962E-02	-.3297E-02
53	29.345	0.4164E-05	-.1570E-04	-.4634E-05
54	29.670	0.2779E-02	-.8639E-02	-.1765E-02
55	31.959	-.6539E-01	-.2392E-02	-.2078E-01
56	32.833	0.1412E-01	-.1261E-01	0.3278E-01
57	33.324	-.7284E-06	0.5322E-06	0.7398E-06
58	33.329	-.4767E-05	0.1225E-05	-.3518E-05
59	33.331	-.6151E-06	0.2991E-05	0.2355E-05
60	33.356	0.7696E-07	-.2058E-05	-.5980E-06
61	33.755	0.5599E-02	-.1923E-01	-.2965E-01
62	34.601	0.1051E-01	0.6828E-02	-.4371E-01
63	38.746	-.2383E-02	-.6005E-02	-.8444E-02
64	41.133	0.1950E-01	-.4149E-02	0.5592E-02
65	41.724	-.7059E-02	-.4430E-02	-.4963E-02
66	43.805	0.2279E-01	0.1176E-02	0.1960E-01
67	46.039	-.6690E-03	0.1740E-02	-.3381E-03
68	46.774	0.3618E-02	0.1139E-01	0.2937E-03
69	52.189	-.2345E-02	0.2038E-02	0.2402E-01
70	53.678	-.4079E-02	-.1187E-01	-.3937E-02
71	56.037	-.2481E-02	-.4485E-02	0.9030E-03
72	57.443	-.1831E-03	-.2345E-02	0.1559E-03
73	60.417	0.5449E-02	-.8519E-02	0.1368E-01
74	61.499	0.2343E-02	0.3762E-02	0.2755E-02
75	63.198	0.3177E-02	-.4234E-02	0.1825E-02
76	65.195	-.1755E-03	-.3160E-02	0.2424E-02
77	70.714	-.4470E-02	0.8027E-03	-.4755E-02
78	72.554	-.6842E-03	0.2165E-02	-.1378E-02
79	72.850	-.2813E-02	0.2153E-04	-.1135E-01
80	73.513	0.5732E-13	-.5121E-14	-.6689E-13
81	73.830	0.3987E-07	0.3572E-07	0.9669E-07
82	74.293	0.4285E-03	0.8287E-03	0.5426E-02
83	77.776	0.1032E-02	0.4277E-02	-.5006E-02
84	79.399	-.2265E-02	-.1715E-02	-.8344E-02
85	84.253	0.4545E-02	0.1570E-02	0.4250E-02
86	87.805	-.6527E-03	0.1018E-02	-.1919E-02
87	97.949	0.2215E-02	-.1655E-02	0.7885E-02
88	99.172	0.3890E-02	-.8096E-03	0.1385E-02
89	104.967	-.7456E-02	0.2126E-02	-.7777E-03
90	106.887	0.7992E-02	0.1626E-02	0.1391E-01
91	107.630	0.1531E-02	-.1353E-02	-.1734E-02
92	112.129	0.9765E-03	0.3154E-03	0.8478E-02
93	114.245	0.8932E-03	0.2148E-02	-.3439E-02
94	114.871	-.8217E-14	-.1036E-14	0.8846E-14
95	115.621	0.1090E-02	-.2416E-03	-.1590E-02
96	116.412	0.1080E-06	-.4333E-07	0.6044E-07
97	119.099	-.6016E-04	0.4370E-03	0.9195E-04
98	122.151	0.1556E-02	0.1645E-02	0.2502E-02
99	123.862	0.1775E-02	-.8444E-03	-.5030E-02
100	127.143	-.1758E-02	0.4654E-02	-.4293E-02
101	129.399	-.3709E-02	0.1164E-02	-.7794E-02
102	136.398	-.1356E-03	0.2072E-02	0.5545E-02
103	136.446	0.2937E-02	0.1920E-02	0.2138E-03
104	140.536	-.1947E-02	-.8602E-04	0.3327E-02
105	141.447	-.3233E-03	0.2992E-02	0.7711E-04
106	144.816	0.4310E-03	-.1334E-02	0.5242E-02
107	146.063	-.7033E-03	-.4956E-02	-.3082E-02
108	147.833	0.3421E-03	0.1752E-02	-.2428E-02
109	154.900	0.1284E-02	0.4461E-03	-.4775E-02
110	156.024	-.2166E-03	0.1605E-02	0.1514E-02
111	158.634	-.1109E-02	-.1000E-02	-.2531E-02
112	159.792	-.3527E-02	0.8519E-03	-.8458E-02
113	163.294	-.9617E-03	0.1130E-03	-.1783E-02
114	163.678	0.1831E-03	-.1196E-02	0.9422E-04
115	169.528	-.5951E-03	-.3701E-03	0.1387E-03
116	173.140	-.5497E-03	0.1010E-02	0.1929E-02
117	177.783	-.2961E-06	-.3091E-03	0.1400E-02
118	178.984	-.6780E-03	0.3023E-03	0.1443E-02
119	183.455	0.8591E-03	-.1740E-03	0.1299E-02
120	183.708	-.8814E-04	0.2801E-03	0.1375E-02
121	185.574	0.9748E-03	-.9084E-03	-.4031E-02
122	187.134	0.2476E-02	0.3247E-03	0.1224E-01
123	197.901	-.8149E-03	0.6895E-03	0.2083E-02
124	205.905	0.1153E-02	-.6374E-03	0.1176E-01
125	207.733	0.2965E-03	0.1695E-02	0.3375E-02
126	214.931	0.6214E-02	-.6000E-02	-.6966E-02
127	215.240	0.2675E-02	0.5615E-03	0.1469E-01
128	219.442	-.7244E-03	0.5531E-03	-.1840E-02
129	220.762	-.2509E-02	-.2675E-02	-.1032E-02
130	227.008	0.1002E-02	0.1359E-03	0.1627E-02
131	231.066	0.7337E-05	-.2353E-03	-.1771E-02
132	234.869	0.3960E-02	0.4031E-02	-.8614E-02
133	241.078	0.9821E-03	0.6534E-03	0.7271E-03
134	244.629	-.4445E-04	-.2472E-02	-.1596E-02
135	249.454	0.7256E-04	0.2936E-03	-.9663E-02
136	258.552	-.4418E-02	-.4399E-04	-.7507E-02
137	266.619	-.4646E-04	0.2489E-02	-.2898E-04
138	275.833	0.1692E-03	0.2223E-02	-.4779E-03
139	278.953	-.1535E-02	-.1933E-03	0.4192E-02
140	287.187	0.2177E-02	0.7193E-03	-.1909E-02
141	289.542	-.1469E-03	0.1130E-02	-.2800E-03
142	292.944	0.8417E-05	-.8588E-04	0.8193E-04
143	298.738	-.2699E-03	0.4304E-05	0.1281E-02
144	300.429	-.4850E-03	-.8453E-04	0.5642E-03
145	304.112	-.7969E-04	-.2095E-04	0.7059E-04
146	325.368	0.9380E-05	0.2396E-03	0.5419E-04
147	307.073	-.2356E-13	0.6394E-15	0.2271E-13
148	387.074	0.4021E-12	0.7004E-11	-.4093E-12
149	391.407	-.1993E-13	0.5730E-15	0.1921E-13
150	391.408	-.4675E-12	-.7291E-11	[illegible]
151	428.985	0.3976E-04	0.8044E-05	[illegible]
152	428.986	-.1626E-04	0.1074E-04	-.3129E-04
153	499.528	0.1122E-04	-.4953E-05	0.3925E-05
154	494.333	-.1567E-05	-.1797E-05	[illegible]
155	73174.187	[illegible]	0.3132E-04	[illegible]
156	73795.687	0.2290E-01	[illegible]	-.2313E-01

SECTION 3

STRENGTH CONTROLLED DESIGN

3.1 Introduction

The strength controlled design (Revision 3) was created by resizing the structural members in the updated ACOSS Model #2 (Revision 1) to meet the minimum requirements for local stability and frequency. The non-structural mass due to the mirrors and solar panels, which represents 90% of the total system mass in revision 1, is unchanged in this design. Because of this, even though the structural mass was reduced by 50% the total mass was reduced by only 373 kg to 8963 kg. This results in a very flexible structure with very low natural frequencies.

The design constraints were established to prevent local failure of individual elements in the structure due to buckling or excessive dynamic interaction due to low member natural frequency. The local buckling load, P_{cr}, is directly related to the slenderness (l/r) of each beam by the formula:

$$P_{cr} = \frac{\pi^2 EA}{(K \cdot \frac{l}{r})^2}$$

since the element forces are expected to be small, a slenderness limit of l/r = 400 was used, and K equals .7 to account for end fixity. Using this equation, the minimum buckling load in the structure is 1060N. The natural frequency of each member was constrained to be greater than 10 Hz to prevent significant interaction between system vibratons and local vibrations. Finally, the wall thickness of the tubes was constrained to be a minimum of .03 cm. The NASTRAN input deck is listed in Appendix B. The tubular truss elements used to support the primary and tertiary mirrors were not changed. Reducing the size of these elements would have resulted in an unsound structure design due to the very low frequency local vibrations of these mirrors. These local effects would not be present in actual systems and would yield misleading results for this test model. The mass properties of this design are listed in Table 3.1.

3.2 Analysis

A normal modes analysis of the finite element model containing all of the changes, Revision 3, was performed using the MSC/NASTRAN finite element program. The resulting frequencies are shown in Table 3.2 along with the LOS errors for each mode. These LOS errors are based on a unit amplitude for each mode assuming they have been normalized to a unit generalized mass.

Table 3.1. Lumped mass distribution

node	structural mass (kg)	non-struct. mass (kg)	node	structural mass (kg)	non-struct. mass (kg)
1	.80		36	2.68	
2	5.37		37	4.41	
3	10.72		38	4.41	
4	7.35		39	2.68	
5	5.37		40	9.48	
6	10.67		42	0.0	
7	.80		43	2.10	
8	7.59		44	0.0	3500.
9	14.12	67.4	45	2.10	
10	8.70	67.4	46	0.0	
11	14.12	67.4	47	0.0	
12	8.72	67.4	48	2.62	81.91
13	7.59		49	5.25	
14	12.12		50	5.25	163.82
15	17.25		51	5.25	
16	25.78		52	4.73	73.82
17	17.25		53	4.73	73.82
18	25.78		54	5.25	
19	12.12		55	5.25	163.82
26	10.78		56	5.25	
27	15.50	69.50	57	2.62	81.91
28	38.49	6.74	910	3.57	
29	10.80	69.50	1001		1000.0
30	43.19	6.74	1002		800.0
31	10.78		1003		1200.0
32	39.20	6.74	1004		600.0
33	42.17	6.74	1112	3.60	
34	11.51	69.50	2830	62.76	
35	8.54	69.50	3233	62.76	
Totals				649.97	8313.66

Total mass = 8963 kg

Center of Mass Location

x = 0.0 m

y = -0.240 m

z = 6.991 m

Table 3.2. ACOSS Model #2: Revision 3

NODE	FREQ(HZ)	LOSX	LOSY	DEFOCUS
1	0.0	0.1637E-14	-.1177E-09	-.1029E-14
2	0.0	-.1023E-08	0.2809E-14	-.7944E-15
3	0.0	-.2154E-13	-.2378E-14	-.1731E-08
4	0.0	0.9306E-03	-.7743E-14	0.1045E-08
5	0.0	0.1306E-06	-.9047E-03	0.1453E-12
6	0.0	0.1009E-07	-.6662E-04	0.1103E-13
7	0.114	-.1513E-06	0.2207E-03	-.3412E-05
8	0.147	-.4974E-05	-.2335E-06	0.3185E-05
9	0.150	-.1678E-03	-.9384E-09	-.8232E-06
10	0.175	-.1374E-05	-.1204E-03	0.1901E-05
11	0.455	-.1047E-04	-.6797E-05	0.8500E-04
12	0.557	0.2471E-05	0.7663E-03	0.1431E-04
13	0.596	-.8838E-03	0.9047E-08	-.8065E-04
14	0.615	-.6298E-05	-.5541E-03	0.3427E-05
15	0.636	-.2323E-03	0.2751E-05	-.6674E-04
16	0.642	0.8353E-05	-.7826E-04	-.1256E-04
17	0.815	-.3501E-04	-.1306E-05	0.7612E-05
18	0.816	-.1054E-03	0.6144E-06	-.2771E-04
19	0.823	-.2942E-13	-.9640E-16	-.1626E-15
20	0.916	-.3398E-04	-.3563E-05	0.3586E-04
21	0.972	-.1047E-04	-.4472E-03	0.1385E-04
22	1.159	-.2313E-06	-.2838E-02	-.4502E-04
23	1.551	0.2201E-04	0.2013E-01	0.2520E-03
24	1.773	0.4702E-04	0.8534E-03	-.1182E-03
25	2.250	-.1012E-12	-.3082E-15	-.3790E-16
26	2.254	0.3360E-05	0.6148E-07	-.3122E-05
27	3.434	-.4886E-12	0.3377E-14	0.2880E-17
28	3.452	-.5544E-05	-.2212E-06	0.5171E-05
29	3.957	-.7354E-05	-.1306E-06	-.1644E-04
30	3.967	0.2073E-05	0.4305E-06	-.2214E-04
31	4.052	0.8105E-06	-.3969E-04	0.2638E-06
32	4.338	0.1844E-06	-.1349E-03	-.2936E-06
33	6.563	-.2192E-01	-.5622E-04	-.6466E-01
34	8.065	0.1188E-02	0.1300E-01	-.6518E-02
35	8.453	0.1993E-02	0.1631E-02	0.5918E-01
36	8.854	-.2209E-03	-.9022E-03	0.1289E-01
37	9.010	-.1421E-01	0.2431E-02	0.2635E-01
38	10.340	0.1817E-02	0.1794E-01	-.5568E-02
39	10.523	0.1415E-02	0.8693E-02	0.2043E-03
40	11.550	0.1690E-01	-.4415E-01	0.1334E-01
41	11.651	0.9554E-06	-.4623E-05	0.2162E-06
42	11.652	-.6264E-05	-.4098E-05	-.5652E-05
43	11.652	0.2878E-04	-.3229E-04	0.2348E-04
44	11.661	-.3909E-04	0.5767E-04	-.3144E-04
45	11.841	0.2795E-01	0.3078E-01	0.2469E-01
46	13.497	-.2979E-01	0.7018E-02	-.1897E-01
47	14.194	-.3922E-01	0.1879E-02	-.5539E-01
48	15.030	0.6588E-02	0.2534E-01	0.6388E-02
49	16.741	0.2155E-02	0.8378E-03	-.5170E-01
50	17.322	-.1753E-02	0.9305E-02	-.2498E-02
51	17.613	0.1322E-01	-.1624E-03	0.9533E-02
52	17.767	-.9940E-06	-.3020E-06	0.1237E-05
53	17.768	-.6065E-06	0.4776E-05	-.8795E 07
54	17.769	-.1349E-05	-.4390E-06	-.4134E-05
55	17.777	-.5899E-06	-.4628E-05	-.2865E-06
56	21.317	0.4011E-01	0.3962E-03	-.3428E-01
57	21.681	0.2915E-15	-.8912E-15	-.3480E-15
58	22.165	-.7403E-04	-.2409E-01	0.4159E-02
59	23.891	0.1758E-01	-.3848E-02	-.6371E-01
60	23.944	0.7349E-04	0.1162E-04	-.2542E-03
61	24.559	0.3863E-03	0.4230E-02	0.2523E-02
62	24.660	0.1050E-01	0.8207E-04	-.2234E-01
63	25.693	0.6992E-02	0.1194E-01	-.7809E-03
64	26.110	0.1697E-01	-.6579E-03	0.5574E-02
65	26.798	0.2987E-01	0.5931E-02	0.2687E-01
66	28.411	0.2695E-01	-.1081E-01	0.3053E-01
67	29.016	0.1950E-02	-.4954E-02	0.1306E-03
68	32.375	-.2862E-02	-.1507E-01	0.4530E-02
69	33.112	-.8899E-02	-.2291E-02	0.2921E-01
70	33.542	0.6071E-03	0.9511E-02	0.2196E-01
71	35.370	-.1054E-02	0.7359E-02	0.3449E-02
72	36.599	-.4004E-02	0.8649E-03	0.9467E-02
73	39.439	0.5492E-02	0.3090E-02	-.1991E-01
74	40.170	0.6103E-03	0.1727E-02	-.1893E-02
75	40.633	0.9347E-03	-.3596E-02	-.5976E-02
76	42.844	0.4378E-03	-.2972E-02	0.1165E-02
77	44.116	0.7552E-02	0.1568E-02	-.1012E-01
78	45.241	-.4648E-02	0.2254E-02	0.1052E-01
79	49.699	-.1994E-02	-.4166E-02	-.3913E-02
80	50.671	-.6317E-03	0.4997E-02	-.3560E-02
81	54.458	0.1432E-02	-.1799E-02	0.7890E-02
82	55.558	-.1485E-03	-.4424E-02	-.3416E-02
83	59.887	-.1099E-16	-.6384E-17	-.2401E-17
84	60.129	-.6912E-07	-.5003E-07	-.1725E-06
85	61.339	-.1397E-02	-.2063E-02	-.2147E-04
86	63.528	-.1482E-02	-.9710E-03	-.1942E-01
87	64.270	0.2112E-04	0.6196E-03	0.3222E-02
88	67.163	-.5622E-02	0.6091E-03	-.1526E-01
89	69.498	0.2391E-03	-.7217E-03	0.8870E-03
90	70.874	0.5584E-02	-.3206E-03	0.1061E-01
91	72.243	-.2048E-02	0.9027E-03	-.4744E-02
92	74.935	0.8392E-03	-.2156E-02	0.1009E-02
93	76.704	-.1378E-01	0.4236E-05	0.2404E-02
94	79.755	-.2222E-03	0.2019E-03	0.3004E-03
95	86.536	0.8548E-02	0.8259E-04	-.1169E-01
96	94.263	0.2195E-17	0.1431E-17	-.1594E-17
97	95.376	-.4447E-02	0.2252E-02	0.5679E-02
98	95.495	0.5469E-05	-.1495E-05	-.6926E-05
99	96.093	0.3025E-02	0.4132E-02	-.3511E-02
100	99.325	0.6422E-02	-.3595E-03	-.5844E-02
101	102.489	-.3311E-03	-.2398E-02	0.1086E-02
102	102.705	-.1070E-02	0.1379E-02	0.2415E-02
103	108.858	0.9167E-05	0.2229E-02	0.1145E-03
104	109.695	0.4806E-02	0.2632E-04	-.1675E-02
105	111.198	-.1067E-04	0.3881E-03	-.2490E-02
106	112.074	0.2379E-03	-.1711E-02	-.8295E-03
107	114.974	0.9663E-03	0.1523E-03	-.1346E-03
108	117.639	0.4818E-03	0.1083E-02	0.3942E-03
109	118.199	0.1559E-03	0.4376E-03	-.2529E-02
110	119.915	-.2610E-02	-.3872E-03	-.5290E-02
111	120.998	0.5274E-02	-.8547E-03	0.2395E-02
112	131.127	-.1973E-02	0.1581E-03	-.3275E-02
113	132.091	-.7368E-04	-.1593E-02	-.2698E-03
114	135.631	0.2330E-02	-.3408E-03	-.5439E-02
115	139.911	0.1018E-02	-.3292E-02	0.1878E-03
116	140.196	-.1949E-02	-.2409E-02	0.1501E-02
117	140.954	0.6685E-03	0.4529E-03	0.1615E-01
118	142.352	0.4545E-03	-.1522E-02	-.5856E-02
119	143.436	-.6365E-04	0.1808E-02	-.2002E-02
120	144.897	0.1574E-02	-.9695E-03	0.7227E-02
121	154.044	0.2135E-03	-.5861E-03	-.2528E-02
122	157.527	-.5346E-03	-.8743E-03	0.7692E-03
123	160.629	-.2481E-03	-.8585E-03	0.1710E-02
124	164.823	0.2037E-02	-.2806E-02	-.2010E-02
125	165.339	0.1553E-02	-.7530E-03	-.3562E-02
126	169.179	0.1567E-02	-.2314E-02	-.5946E-02
127	169.816	0.1733E-02	-.1606E-02	-.1486E-02
128	173.988	0.3064E-03	0.5902E-03	-.2560E-02
129	183.641	-.5348E-03	0.4362E-03	-.1784E-02
130	183.923	0.6928E-03	0.1536E-02	0.1394E-03
131	188.640	0.2352E-03	-.4086E-04	0.3359E-03
132	193.180	-.1407E-02	0.2262E-03	0.1339E-02
133	197.432	0.7819E-03	-.6222E-03	-.2947E-02
134	200.285	0.1908E-02	0.7556E-03	-.3444E-02
135	206.248	0.1327E-02	0.1739E-02	-.2921E-02
136	210.842	-.2314E-03	-.7780E-03	-.1820E-03
137	211.115	0.7208E-04	-.6526E-03	-.1387E-03
138	213.294	-.9530E-03	-.2013E-03	0.1339E-02
139	232.302	0.1593E-02	0.1774E-02	-.2716E-02
140	236.788	-.7737E-03	-.8215E-03	0.1301E-02
141	237.321	0.1139E-03	-.4270E-04	-.1225E-02
142	244.598	-.6822E-03	-.2367E-03	0.1262E-02
143	261.883	-.1735E-02	0.2351E-04	-.3109E-02
144	272.788	-.8487E-05	-.3367E-04	-.1690E-04
145	273.877	0.5170E-03	-.4068E-05	0.8664E-03
146	291.365	0.8617E-05	0.2812E-03	0.5558E-05
147	318.313	0.6732E-05	0.6640E-05	-.1172E-05
148	319.934	-.1155E-04	0.2529E-04	0.1054E-05
149	385.396	0.3056E-17	0.1751E-16	0.3546E-17
150	385.396	0.2800E-12	0.1480E-11	0.2114E-12
151	387.946	0.3739E-05	0.4073E-05	-.2981E-04
152	387.946	-.2229E-05	0.6991E-05	0.1768E-04
153	388.299	-.1155E-17	-.4143E-17	-.5477E-18
154	388.299	-.2354E-12	-.1402E-11	-.2222E-12
155	503.257	0.1367E-05	0.1513E-05	0.1467E-07
156	503.659	0.1292E-05	-.6126E-05	-.1213E-07

SECTION 4

STIFFNESS CONTROLLED DESIGN

4.1 Introduction

The stiffness controlled structural design (Revision 4) is one component of the passively controlled system. In theory, the penalty paid for the increased mass of the stiffened system will be offset by a lighter, less complex passive control system. This will be true if the effect of the disturbances is reduced significantly by local stiffening or increasing the natural frequencies of the system.

The design of a stiffened structure can be approached in a number of ways depending on the desired results. The simplest approach is to use a trial and error method based on engineering judgement to increase member sizes and natural frequencies. At the other end of the spectrum are optimization techniques in which a performance index, which is a function of structural parameters, is optimized subject to constraints on the variables. The computation requirements for this type of approach can be extensive. The approach which was used to generate this model falls between these two extremes.

The objective of the redesign of this system is to improve the performace by reducing the effects of the disturbances. This is complicated by the fact that most of the elastic modes, except for those of the solar panels, will be excited by the disturbances and cause LOS errors. Normal improvement approaches employing frequency separation between the disturbances and the structural modes will not be effective because of the high bandwidth of these forces. It will be impossible to add sufficient stiffness to raise the low frequency bending modes above 15 Hz. The maximum achievable frequency of these modes may be well below this point. Based on the considerations, the goal of this redesign will be to raise all frequencies of the optical support truss as much as possible and to raise the solar panel modes out of the bandwidth of the isolator modes.

Starting with the baseline design (Revision 1) a maximum mass model was generated by increasing the size of all members to the maximum permitted by the constraints.

Radius/thickness = 50

Length/radius = 40

Maximum thickness = 1.0 cm

The maximum allowable area based on these constraints is the minimum of:

$$AMAX1 = 2\Pi \cdot L/_{40} \cdot L/_{40} \cdot 1/50 = 7.854 \times 10^{-5} L^2$$

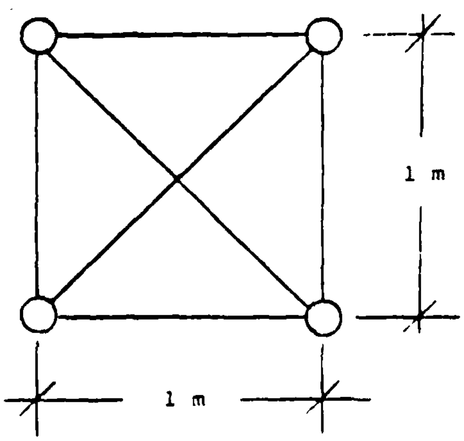
$$AMAX2 = 2\Pi \cdot L/_{40} \cdot .01 = 1.5708 \times 10^{-3} L$$

AMAX1 controls for all members in this model since it has the minimum value for elements with length less than twenty meters. The structural mass required for the maximum mass design is

$$Mass = \Sigma A_i L_i \rho$$

This must be scaled to meet the structural mass constraint of 6686 kg and total constraint of 15000 kg. All areas will be scaled uniformly to meet these constraints. Since the member areas are proportional to L^2, the stiffness matrix in both the axial and bending directions is proportional to the length L. If there is a wide range of lengths in the model, the shorter elements may not have sufficient strength. An analysis of this design showed significant strain energy in the short elements of the lower optical support truss. This was corrected by modifying the mass scale factor to account for the inverse of the length. This will result in areas which are proportional to the length and axial stiffness which is independent of length and equal for all elements. Analysis results using these modified section properties showed a significant improvement in frequency and a better distribution of strain energy.

To raise the frequencies of the solar panels above 1 Hz, and avoid overly large sections, the solar panel support booms were redesigned as a truss. The design, shown in Figure 4.1, is modelled by an equivalent beam in the finite element model.



Tube Properties:

Radius = 0.05 m

t = 0.001 m

Area = 0.000314 m^2

Section Properties:

Area = 4 A_{tube} = 0.001257 m^2

I = 0.000314 m^4

J = 0.000628 m^4

Mass/L = 3.82 kg/m

Figure 4.1. Solar panel support boom design

The section properties of the members in this design are listed in Appendix C. The structural and non-structural mass lumped at each node point are listed in Table 4.1.

4.2 Analysis

A normal modes analysis of the finite element model of the stiffness controlled design, Revision 4, was performed using the MSC/NASTRAN finite element program. The resulting frequencies are shown in Table 4.2 along with the LOS error for each mode. These LOS errors are based on a unit amplitude for each mode assuming they have been normalized to a unit generalized mass.

Table 4.1. Lumped mass distribution - Revision 4

node	structural mass (kg)	non-struct. mass (kg)	node	structural mass (kg)	non-struct. mass (kg)
1	29.22		36	96.98	
2	113.01		37	126.20	
3	209.68		38	126.20	
4	123.35		39	96.98	
5	113.01		40	134.51	
6	207.15		42	0.0	
7	29.22		43	11.96	
8	151.76		44	0.0	3500.
9	195.78	67.4	45	11.96	
10	164.84	67.4	46	0.0	
11	195.78	67.4	47	0.0	
12	165.76	67.4	48	14.96	81.91
13	151.76		49	29.91	
14	196.39		50	29.91	163.82
15	269.43		51	29.91	
16	305.14		52	26.92	73.82
17	269.43		53	26.92	73.82
18	305.14		54	29.91	
19	196.39		55	29.91	163.82
26	189.90		56	29.91	
27	270.24	69.50	57	14.96	81.91
28	185.98	6.74	910	125.08	
29	195.18	69.50	1001		1000.0
30	261.05	6.74	1002		800.0
31	189.90		1003		1200.0
32	168.94	6.74	1004		600.0
33	214.79	6.74	1112	126.70	
34	209.38	69.50	2830	62.76	
35	163.52	69.50	3233	62.76	
Totals				6686.40	8313.66

Total mass = 15000 kg

Center of Mass Location

x = 0.0 m

y = -0.201 m

z = 3.838 m

Table 4.2. ACOSS Model #2: Revision 4

MODE	FREQ(HZ)	LOSX	LOSY	DEFOCUS
1	0.0	0.2423E-14	-.9048E-10	-.7644E-16
2	0.0	-.7899E-09	0.1625E-13	-.3702E-15
3	0.0	-.1892E-12	0.4189E-13	-.1339E-08
4	0.0	0.7281E-03	0.3454E-14	0.8221E-09
5	0.0	0.9702E-06	-.7085E-03	0.1095E-11
6	0.0	0.5774E-07	-.3305E-04	0.6514E-13
7	0.141	-.3548E-04	0.3209E-03	-.1604E-06
8	0.278	-.1494E-06	-.8981E-04	0.2230E-06
9	0.371	-.3758E-04	-.1820E-06	0.1760E-05
10	0.449	-.5288E-03	-.4116E-05	-.2273E-05
11	0.467	-.6048E-05	0.5442E-03	0.3415E-06
12	0.647	-.2997E-04	0.4488E-07	0.1892E-05
13	1.305	-.1913E-04	-.4498E-07	-.6670E-06
14	1.346	0.3680E-06	0.7921E-07	-.1315E-05
15	3.145	-.7695E-04	-.9709E-05	0.6845E-06
16	3.893	-.3945E-06	0.3818E-04	0.8697E-06
17	5.004	-.6909E-04	-.2571E-02	0.4376E-04
18	5.616	0.4149E-04	-.1092E-01	-.1733E-03
19	6.926	-.7421E-06	0.5799E-07	-.4078E-06
20	6.968	0.1895E-06	-.3528E-08	-.5605E-06
21	7.735	0.5825E-13	-.3582E-15	-.3239E-16
22	7.835	0.1256E-06	0.7363E-06	-.1210E-06
23	8.084	0.9376E-06	0.5110E-07	-.7905E-06
24	9.470	0.5591E-07	0.1732E-04	0.1245E-06
25	11.858	-.1910E-02	-.8612E-04	-.3953E-02
26	12.779	0.3564E-02	0.6784E-03	0.2391E-02
27	12.851	0.1047E-02	-.2578E-02	0.1069E-02
28	13.511	-.1007E-04	-.4695E-04	-.2577E-03
29	21.134	-.2899E-12	0.4002E-15	0.1870E-15
30	21.169	-.6501E-06	-.7249E-08	-.6343E-07
31	23.710	0.2970E-01	-.8217E-04	0.4395E-01
32	26.683	-.6624E-03	0.2659E-04	-.6580E-01
33	27.509	-.1050E-15	-.9001E-16	0.3545E-15
34	28.691	0.1352E-05	-.2768E-07	-.1839E-05
35	28.894	0.3787E-06	-.1819E-06	-.2311E-05
36	29.026	0.3205E-06	0.1808E-05	0.1234E-05
37	29.686	0.3491E-03	0.7331E-02	0.1788E-02
38	31.656	0.8707E-07	-.2205E-05	-.4101E-06
39	31.794	-.3003E-07	0.1193E-05	0.6559E-06
40	32.242	-.5483E-03	-.3043E-02	0.2067E-02
41	32.252	0.5368E-12	0.1495E-12	-.1027E-12
42	32.439	0.5194E-07	0.1567E-06	-.3176E-05
43	34.827	-.2731E-02	-.4974E-03	0.3939E-01
44	38.004	-.1167E-01	0.3064E-02	0.3694E-01
45	39.033	-.1304E-02	-.3794E-01	0.2637E-02
46	42.727	0.1229E-01	-.8419E-02	0.2425E-02
47	44.268	0.4201E-01	0.6041E-02	0.4691E-02
48	44.789	-.9995E-02	0.4549E-02	0.6175E-02
49	45.943	-.1002E-01	-.3926E-02	0.4874E-03
50	46.790	-.6378E-02	0.5272E-02	-.1212E-03
51	51.205	0.1822E-06	0.2387E-07	0.3613E-06
52	51.242	0.3140E-05	-.1512E-05	0.2119E-05
53	51.338	-.5598E-06	0.1694E-05	-.6728E-06
54	51.521	-.2145E-02	0.9085E-02	-.2782E-02
55	51.814	-.1290E-05	0.2766E-05	-.1448E-05
56	51.921	0.9333E-02	0.1739E-03	0.5620E-02
57	54.076	0.2256E-01	-.2141E-02	0.2176E-01
58	56.157	-.5394E-03	0.2702E-02	0.1401E-02
59	59.940	-.9582E-03	0.1236E-01	0.3058E-02
60	61.139	-.1243E-01	-.2123E-02	-.2845E-01
61	63.515	0.1845E-01	0.3543E-02	0.5829E-02
62	65.297	-.2571E-02	0.2091E-02	-.1219E-02
63	66.555	0.6943E-03	-.1602E-01	0.7723E-02
64	68.310	0.2381E-04	0.7090E-02	0.1244E-01
65	69.685	0.1300E-02	0.1641E-02	-.2777E-01
66	72.661	0.6038E-02	-.8827E-02	-.8691E-02
67	75.644	-.1080E-01	0.4276E-02	-.3361E-03
68	77.174	0.7128E-02	0.1119E-01	-.4456E-02
69	77.739	-.7716E-07	-.1095E-06	-.3310E-06
70	77.793	0.4675E-06	0.6764E-08	-.5239E-06
71	77.798	-.5534E-07	0.1499E-06	0.4784E-06
72	78.186	0.1223E-05	0.1671E-05	0.5208E-06
73	78.441	-.1614E-02	-.7559E-02	-.1367E-01
74	78.449	0.2723E-14	0.1254E-13	0.2360E-13
75	78.945	0.6122E-02	-.5134E-02	-.2016E-01
76	78.999	-.3599E-07	0.6057E-06	0.1458E-05
77	81.274	-.1458E-03	-.4763E-02	0.1924E-02
78	83.055	-.8864E-02	-.2519E-02	0.2386E-01
79	85.168	0.4452E-02	-.8705E-02	0.1465E-01
80	85.930	-.4629E-03	0.1156E-01	0.4962E-02
81	90.312	-.3990E-02	-.2596E-02	0.5612E-02
82	91.779	0.1783E-02	0.4047E-03	-.4701E-02
83	92.489	-.3618E-02	-.2131E-02	-.2386E-02
84	92.773	0.1351E-02	0.1387E-02	-.1924E-02
85	98.423	0.1063E-02	-.1808E-02	0.2086E-02
86	99.689	0.3430E-02	-.1761E-02	0.4597E-02
87	100.523	0.3029E-02	-.6649E-03	0.4103E-02
88	104.895	-.9921E-03	-.1860E-02	-.6470E-02
89	105.838	0.7171E-02	-.7161E-03	0.4206E-02
90	109.051	-.5397E-02	0.7852E-03	-.8037E-02
91	116.834	-.1272E-02	-.1202E-03	0.2760E-02
92	117.555	-.1824E-17	0.2433E-18	0.4607E-17
93	119.409	-.4461E-08	-.4771E-07	0.1627E-07
94	121.105	0.5598E-02	0.7792E-03	-.1057E-01
95	122.452	0.3738E-02	-.6320E-02	-.7161E-02
96	123.287	-.3919E-02	0.3734E-02	0.8671E-02
97	125.595	-.7543E-03	-.3407E-02	-.3890E-02
98	126.122	-.4326E-02	-.3676E-02	0.5456E-02
99	127.297	-.2991E-02	-.2954E-02	0.7909E-04
100	128.238	0.4313E-02	-.1762E-02	0.6915E-02
101	130.710	0.8257E-03	0.5918E-03	0.1343E-01
102	131.467	-.4160E-02	0.2357E-02	0.5075E-02
103	132.741	-.1523E-02	-.4136E-02	0.5242E-02
104	135.324	0.3052E-02	-.5959E-02	-.4469E-02
105	136.166	0.2860E-03	0.5572E-02	-.6325E-02
106	138.043	-.6688E-02	-.1873E-02	-.8415E-02
107	138.485	0.4185E-02	-.3137E-02	-.7906E-02
108	140.797	0.3352E-02	-.5305E-02	0.5367E-02
109	141.534	0.1603E-02	0.1297E-02	0.2720E-02
110	143.867	-.6327E-02	0.3901E-02	0.1158E-02
111	147.051	-.2116E-02	-.5916E-02	-.1205E-01
112	147.716	0.5188E-02	-.4728E-02	0.2803E-02
113	150.219	0.2172E-02	0.7479E-03	-.4769E-02
114	151.306	-.8922E-03	0.3934E-02	-.7144E-02
115	152.872	-.5366E-02	0.3724E-03	0.5543E-02
116	155.135	0.1204E-02	-.5634E-02	-.5167E-02
117	159.920	0.1109E-02	0.4252E-02	0.3077E-02
118	160.687	0.5266E-03	0.2629E-02	-.2679E-02
119	161.480	-.1358E-02	-.1133E-02	-.1475E-01
120	163.747	-.1536E-02	-.3194E-02	0.3962E-02
121	163.942	-.1780E-02	-.1159E-02	0.7290E-02
122	165.756	-.3109E-02	-.1220E-02	0.9248E-02
123	168.052	0.2908E-02	0.2633E-02	-.9578E-02
124	169.261	-.6341E-02	0.3303E-02	0.1517E-01
125	171.174	0.2024E-03	-.4217E-02	-.3915E-02
126	173.651	0.2829E-02	-.4446E-03	-.3986E-02
127	175.770	-.2054E-02	-.3430E-02	0.1233E-01
128	177.875	-.1135E-03	-.4050E-02	-.2093E-02
129	185.072	0.2532E-02	-.1834E-02	-.7819E-02
130	188.516	0.3110E-03	-.2027E-03	-.2473E-02
131	189.341	-.4938E-03	0.8462E-04	0.1973E-02
132	196.230	0.1201E-02	-.1717E-02	-.2782E-02
133	196.618	-.1128E-02	0.5189E-03	0.4844E-02
134	197.302	-.9306E-03	0.1222E-02	0.1431E-02
135	199.020	-.1698E-02	-.1709E-02	0.2856E-02
136	205.877	-.8170E-04	0.9111E-03	-.1151E-02
137	212.588	-.1249E-03	0.6570E-04	-.6920E-04
138	214.778	0.6951E-03	-.4754E-03	-.1266E-02
139	224.868	-.2130E-03	0.4484E-03	0.1314E-04
140	227.004	-.3680E-03	-.2489E-03	-.3675E-03
141	228.722	-.7933E-03	0.1758E-03	-.1483E-03
142	239.862	-.3578E-17	-.2523E-17	0.1122E-16
143	239.875	-.1931E-09	0.5013E-08	-.4623E-09
144	241.435	-.9549E-04	0.1205E-02	-.1771E-04
145	242.196	-.3338E-03	-.6014E-03	0.4594E-03
146	246.060	0.1596E-02	0.5379E-04	-.5851E-03
147	247.542	0.1622E-17	-.3501E-19	-.4551E-17
148	247.555	-.2380E-09	0.2373E-08	0.6849E-10
149	252.731	-.2289E-04	0.1700E-32	0.1477E-03
150	253.078	0.6561E-03	-.3362E-04	-.1510E-02
151	258.111	-.2654E-03	-.5866E-04	-.6555E-03
152	258.441	0.4061E-04	-.6967E-03	0.6065E-04
153	300.990	-.1913E-03	-.9952E-05	-.2431E-03
154	301.594	0.4708E-06	-.2066E-03	0.2082E-04
155	417.994	0.5745E-05	-.2339E-04	-.9536E-07
156	420.562	-.6392E-05	-.7395E-05	-.4001E-06

SECTION 5

SUMMARY

In order to meet the needs of the VCOSS program for two models which represent the extremes of structural stiffness and were detailed enough to allow specification of control sytem hardware, modifications were made to the design of ACOSS Model #2. Three new revisions of this model were created and are described in this report. The MSC/NASTRAN input for each revision is included in an Appendix.

The first model, Revision 1, is an updated version of the original design, Revision 0. The design has been changed to add more detail to the models of the mirrors, mirror support structure and equipment section. The basic geometry and the stiffness of the structural members were not changed from the original ACOSS Model #2. The dynamic characteristics of this model are close to those exhibited by Revision 0.

Using this updated model as a baseline, two new revised models were created. These two new revised models, a lightweight, flexible design (Revision 3) and a heavy, stiff design (Revision 4) can be used to study the trade-offs between structural mass and control system complexity.

APPENDIX A

```
ID DRAPER,MODEL2
SOL 3
CHKPNT YES
TIME 10
CEND
TITLE =  ***** ACOSS MODEL #2 *****
SUBTITLE = UPDATED ORIGINAL MODEL - REV 1
MPC = 100
METHOD = 600
DISP = ALL
$ESE =ALL
BEGIN BULK
PARAM,USETPRT,1
PARAM   GRDPNT  0
EIGR    600     GIV                                     200                     +10
+10     MASS
$
$     KINEMATIC MOUNT:  TERTIARY MIRROR
$
RBE1,1003,27,123,29,23,3233,3,,+RB31
+RB31,UM,1003,123456
$
$     KINEMATIC MOUNT:  PRIMARY MIRROR
$
RBE1,1001,34,123,35,23,2830,3,,+RB11
+RB11,UM,1001,123456
$
$     KINEMATIC MOUNT:  FOCAL PLANE
$
RBE1,1004,11,123,9,23,40,3,,+RB41
+RB41,UM,1004,123456
$
$     KINEMATIC MOUNT:  SECONDARY MIRROR
$
RBE1,1002,910,123,1112,23,40,3,,+RB21
+RB21,UM,1002,123456
$
$      RIGID EQUIPMENT SECTION
$
RBE2    141     44      123456  42      43      45      46      47
$
$  NODE POINT LOCATIONS
$       NODE #                  X(M)    Y(M)    Z(M)
$
GRID    1                       -7.0    0.0     0.0
GRID    2                       -4.0    5.0     0.0
GRID    3                       -4.0    -5.0    0.0
GRID    4                       0.0     5.0     0.0
GRID    5                       4.0     5.0     0.0
GRID    6                       4.0     -5.0    0.0
GRID    7                       7.0     0.0     0.0
GRID    8                       -7.0    0.0     2.0
GRID    9                       -4.0    5.0     2.0
GRID    1004                    0.0     4.0     2.0
GRID    10                      -4.0    -5.0    2.0
GRID    910                     -4.0    -2.5    2.0
GRID    1112                    4.0     -2.5    2.0
```

```
GRID    11              4.0     5.0     2.0
GRID    12              4.0     -5.0    2.0
GRID    13              7.0     0.0     2.0
GRID    14              -6.0    0.0     12.
GRID    15              -4.0    4.0     12.
GRID    16              -4.0    -4.0    12.
GRID    17              4.0     4.0     12.
GRID    18              4.0     -4.0    12.
GRID    19              6.0     0.0     12.0
GRID    26              -5.0    0.0     22.0
GRID    27              -4.0    3.0     22.0
GRID    28              -4.0    -3.0    22.0
GRID    2830            0.0     -3.0    22.0
GRID    1001            0.0     -6.5    22.0
GRID    29              4.0     3.0     22.0
GRID    30              4.0     -3.0    22.0
GRID    31              5.0     0.0     22.0
GRID    32              -4.0    10.0    22.0
GRID    3233            0.0     10.0    22.0
GRID    1003            0.0     6.5     22.0
GRID    33              4.0     10.0    22.0
GRID    34              -4.0    -10.0   22.0
GRID    35              4.0     -10.0   22.0
GRID    36              -4.0    3.0     24.0
GRID    37              -4.0    -3.0    24.0
GRID    38              4.0     3.0     24.0
GRID    39              4.0     -3.0    24.0
GRID    40              0.0     2.5     2.0
GRID    1002            0.0     0.0     2.0
GRID    42              0.0     5.0     -0.3
GRID    43              -2.0    0.0     -1.3
GRID    44              0.0     -1.667  -1.3
GRID    45              2.0     0.0     -1.3
GRID    46              -4.0    -5.0    -0.3
GRID    47              4.0     -5.0    -0.3
GRID    48              -26.0   0.0     -1.3
GRID    49              -21.00  0.0     -1.3
GRID    50              -16.0   0.0     -1.3
GRID    51              -11.0   0.0     -1.3
GRID    52              -6.0    0.0     -1.3
GRID    53              6.0     0.0     -1.3
GRID    54              11.0    0.0     -1.3
GRID    55              16.0    0.0     -1.3
GRID    56              21.00   0.0     -1.3
GRID    57              26.0    0.0     -1.3
GRID    100             0.0     0.0     0.0             456
$
$  ELEMENT CONNECTION DATA
$
$       ELEM#   PROP#   NODE    NODE    LOCAL AXIS ORIENTATION VECTOR
$
BAROR                                   1.0     0.0     0.0     1
CBAR    1       200     1       2
CBAR    2       200     1       3
CBAR    3       200     2       3
CBAR    4       200     2       4       0.0     1.0     0.0     1
CBAR    5       200     3       4
```

CBAR	6	200	4	5	0.0	1.0	0.0	1
CBAR	7	200	4	6				
CBAR	8	200	3	6	0.0	1.0	0.0	1
CBAR	9	200	5	6				
CBAR	10	200	5	7				
CBAR	11	200	6	7				
CBAR	12	200	1	8				
CBAR	13	200	2	9				
CBAR	14	200	3	10				
CBAR	15	200	5	11				
CBAR	16	200	6	12				
CBAR	17	200	7	13				
CBAR	18	200	3	8				
CBAR	19	200	2	8				
CBAR	21	200	4	9				
CBAR	22	200	4	11				
CBAR	24	200	5	13				
CBAR	25	200	6	13				
CBAR	30	200	8	9				
CBAR	31	200	8	10				
CBAR	32	200	9	910				
CBAR	232	200	910	10				
CBAR	33	200	9	40				
CBAR	34	200	910	40				
CBAR	35	200	11	40				
CBAR	36	200	1112	40				
CBAR	201	200	910	1112	0.0	1.0	0.0	1
CBAR	202	200	2	910				
CBAR	203	200	3	910				
CBAR	204	200	5	1112				
CBAR	205	200	6	1112				
CBAR	207	200	12	910				
CBAR	26	200	1112	3				
CBAR	27	200	6	10				
CBAR	37	200	9	11	0.0	1.0	0.0	1
CBAR	38	200	10	12	0.0	1.0	0.0	1
CBAR	39	200	11	1112				
CBAR	239	200	1112	12				
CBAR	40	200	11	13				
CBAR	41	200	12	13				
CBAR	42	300	14	15				
CBAR	43	300	14	16				
CBAR	44	300	16	15				
CBAR	45	300	17	18				
CBAR	46	300	17	19				
CBAR	47	300	18	19				
CBAR	54	300	26	27				
CBAR	55	300	26	28				
CBAR	56	300	27	28				
CBAR	57	300	29	30				
CBAR	58	300	29	31				
CBAR	59	300	30	31				
CBAR	60	300	27	29	0.0	1.0	0.0	1
CBAR	61	300	27	30				
CBAR	62	62	28	2830	0.0	1.0	0.0	1
CBAR	184	62	2830	30	0.0	1.0	0.0	1
CBAR	63	300	27	36				

CBAR	64	300	28	37				
CBAR	65	300	30	39				
CBAR	66	300	29	38				
CBAR	67	300	29	36				
CBAR	68	300	27	37				
CBAR	69	300	28	39				
CBAR	70	300	30	38				
CBAR	71	300	36	37				
CBAR	72	300	37	39	0.0	1.0	0.0	1
CBAR	73	300	39	38				
CBAR	74	300	36	38	0.0	1.0	0.0	1
CBAR	75	300	37	38				
CBAR	127	300	26	37				
CBAR	128	300	26	36				
CBAR	129	300	31	39				
CBAR	130	300	31	38				
CBAR	76	400	8	14				
CBAR	77	400	10	14				
CBAR	78	400	10	16				
CBAR	79	400	16	9				
CBAR	80	400	9	15				
CBAR	181	400	8	15				
CBAR	182	200	6	40				
CBAR	183	200	2	40				
CBAR	186	200	3	40				
CBAR	187	200	5	40				
CBAR	81	400	11	17				
CBAR	82	400	11	18				
CBAR	83	400	12	18				
CBAR	84	400	12	19				
CBAR	85	400	13	19				
CBAR	86	400	13	17				
CBAR	87	400	14	26				
CBAR	88	400	14	28				
CBAR	89	400	16	28				
CBAR	90	400	16	27				
CBAR	91	400	15	27				
CBAR	92	400	15	26				
CBAR	93	400	17	29				
CBAR	94	400	18	29				
CBAR	95	400	18	30				
CBAR	96	400	19	30				
CBAR	97	400	19	31				
CBAR	98	400	17	31				
CBAR	99	400	15	32				
CBAR	100	400	16	34				
CBAR	101	400	17	33				
CBAR	102	400	18	35				
CBAR	111	400	26	32				
CBAR	112	400	27	32				
CBAR	113	400	27	33				
CBAR	114	400	29	33				
CBAR	115	400	31	33				
CBAR	116	62	32	3233	0.0	1.0	0.0	1
CBAR	185	62	3233	33	0.0	1.0	0.0	1
CBAR	117	400	26	34				
CBAR	118	400	28	34				

```
CBAR    119     400     30      34
CBAR    120     400     30      35
CBAR    121     400     31      35
CBAR    122     400     34      35      0.0     1.0     0.0     1
CBAR    123     400     32      36
CBAR    124     400     33      38
CBAR    125     400     34      37
CBAR    126     400     35      39
CBAR    131     500     48      49      0.0     1.0     0.0     1
CBAR    132     500     49      50      0.0     1.0     0.0     1
CBAR    133     500     50      51      0.0     1.0     0.0     1
CBAR    134     500     51      52      0.0     1.0     0.0     1
CBAR    135     500     52      43      0.0     1.0     0.0     1
CBAR    136     500     45      53      0.0     1.0     0.0     1
CBAR    137     500     53      54      0.0     1.0     0.0     1
CBAR    138     500     54      55      0.0     1.0     0.0     1
CBAR    139     500     55      56      0.0     1.0     0.0     1
CBAR    140     500     56      57      0.0     1.0     0.0     1
$
$    ISOLATOR SPRINGS
$
$      ELEM#      K       NODE      DOF      NODE     DOF
$               (N/M)      A         A        B        B
$
CELAS2  142     5.79E3  4        1        42       1
CELAS2  143     5.79E3  4        2        42       2
CELAS2  144     5.79E3  4        3        42       3
CELAS2  145     5.79E3  3        1        46       1
CELAS2  146     5.79E3  3        2        46       2
CELAS2  147     5.79E3  3        3        46       3
CELAS2  148     5.79E3  6        1        47       1
CELAS2  149     5.79E3  6        2        47       2
CELAS2  150     5.79E3  6        3        47       3
$
$  MATERIAL PROPERTY DATA
$
$       MAT #       E               NU       RHO
$
MAT1    100     1.24E+11        0.3      1720.
MAT1    200     1.24E+11        0.3      1720.
MAT1    300     1.24E+11        0.3
$
$
$ LUMPED MASS DATA
$                                                                +XXXX
$CONM2  ELEM#   NODE#                   MASS
$+XXXX   IXX                    IYY                     IZZ
$
$       MIRRORS
$                                                                +1001
CONM2   1001    1001                    1000.
+1001   4083.33                 5333.33                 9416.67
                                                                 +4040
CONM2   1002    1002                    800.
+4040   1666.67                 4266.67                 5933.33
                                                                 +1003
CONM2   1003    1003                    1200.
+1003   4900.                   6400.                   11300.
                                                                 +1004
CONM2   1004    1004                    600.
```

```
+1004   200.            800.                        1000.
$
$       EQUIPMENT SECTION
$
CONM2   544     44              3500.                                   +544
+544    20611.          10500.                      28777.
$
$     SOLAR PANELS
$
CONM2   548     48              81.91                                   +548
+548    270.0
CONM2   550     50              163.82                                  +550
+550    540.0
CONM2   552     52              73.82                                   +552
+552    270.0
CONM2   553     53              73.82                                   +553
+553    270.0
CONM2   557     57              81.91                                   +557
+555    540.0
CONM2   555     55              163.82                                  +555
+557    270.0
$
$    ADDITIONAL NON-STRUCTURAL MASS AT MIRROR SUPPORTS
$
CONM2   501     27              69.5
CONM2   502     28              6.74
CONM2   503     29              69.5
CONM2   504     30              6.74
CONM2   505     32              6.74
CONM2   506     33              6.74
CONM2   507     34              69.5
CONM2   508     35              69.5
CONM2   509     9               67.4
CONM2   510     10              67.4
CONM2   511     11              67.4
CONM2   512     12              67.4
$
$       BEAM SECTION PROPERTIES
$
$       PROP#   MAT#      AREA      IYY       IZZ       J      NSM
$
PBAR    200     100     6.250E-43.095E-63.095E-66.189E-6
PBAR    300     100     3.133E-41.509E-61.509E-63.118E-6
PBAR    400     100     3.919E-43.049E-63.049E-66.099E-6
PBAR    500     100     9.407E-41.874E-51.874E-53.749E-5
PBAR    62      300     6.082E-31.521E-31.521E033.041E-3 15.69
$
$
$
$       MULTI-POINT CONSTRAINT FOR X-AXIS LOS ERROR (NODE 100 DOF 1)
$
MPC*    100                             100                1             -1.0*1000000
*1000000            34                    2   -0.01855287570             *1000001
*1000001                                 34                3   -0.14285714286*1000002
*1000002            35                    2   -0.0185528757              *1000003
*1000003                                 35                3   -0.14285714286*1000004
*1000004          2830                    3    0.28571428572             *1000005
```

```
*1000005                                30          3   0.0            *1000006
*1000006          27                     2   0.08065681999           *1000007
*1000007                                27          3  -0.35489000795*1000008
*1000008          29                     2   0.08065681999           *1000009
*1000009                                29          3  -0.35489000795*1000010
*1000010        3233                     3   0.70978001590           *1000011
*1000011                                33          3   0.0            *1000012
*1000012        1002                     4  -3.48423005566           *1000013
*1000013                                11          2  -0.06210394429*1000014
*1000014           9                     2  -0.06210394429
$
$      MULTI-POINT CONSTRAINT FOR Y-AXIS LOS ERROR (NODE 100 DOF 2)
$
MPC*     100                           100          2            -1.0*2000000
*2000000          34                     1  -0.03710575139           *2000001
*2000001                                34          2  -0.04638218924*2000002
*2000002          34                     3  -0.2500000000            *2000003
*2000003                                35          2   0.04638218924*2000004
*2000004          35                     3   0.2500000000            *2000005
*2000005                                27          1   0.16131363998*2000006
*2000006          27                     2  -0.06049261499           *2000007
*2000007                                27          3  -0.62105751391*2000008
*2000008          29                     2   0.06049261499           *2000009
*2000009                                29          3   0.62105751391*2000010
*2000010        1002                     5   3.48423005566           *2000011
*2000011                                11          1  -0.12420788859*2000012
*2000012          11                     2  -0.07762993037           *2000013
*2000013                                 9          2   0.07762993037*2000014
*2000014
$
$      MULTI-POINT CONSTRAINT EQUATION FOR DEFOCUS (NODE 100 DOF 3)
$
MPC*     100                           100          3            -1.0*3000000
*3000000          34                     3  -0.01912393776           *3000001
*3000001                                35          3  -0.01912393776*3000002
*3000002        2830                     3   0.12749291836           *3000003
*3000003                                30          3   0.0            *3000004
*3000004          27                     3   0.77803217347           *3000005
*3000005                                29          3   0.77803217347*3000006
*3000006        3233                     3  -0.46681930408           *3000007
*3000007                              1002          3  -0.17849008571*3000008
*3000008           9                     3   0.50000000000           *3000009
*3000009                                11          3   0.50000000000*3000010
*3000010          40                     3  -2.00000000000
$
$      RIGID BODY SUPPORT
$
SUPORT,44,123456
ENDDATA

******** END OF MEMBER REV01      391 RECORDS ********
```

APPENDIX B

```
ID DRAPER,MODEL2
SOL 3
CHKPNT YES
CEND
TITLE = ACOSS MODEL #2  - REVISION 3
SUBTITLE = VCOSS DESIGN MODEL
LABEL = 156 MODES AND FREQUENCIES
MPC = 100
METHOD = 600
DISP = ALL
$ESE = ALL
BEGIN BULK
PARAM,USETPRT,1
PARAM   GRDPNT  0
EIGR    600     GIV                                    200                    +10
+10     MASS
$
$     KINEMATIC MOUNT:  TERTIARY MIRROR
$
RBE1,1003,27,123,29,23,3233,3,,+RB31
+RB31,UM,1003,123456
$
$     KINEMATIC MOUNT:  PRIMARY MIRROR
$
RBE1,1001,34,123,35,23,2830,3,,+RB11
+RB11,UM,1001,123456
$
$     KINEMATIC MOUNT:  FOCAL PLANE
$
RBE1,1004,11,123,9,23,40,3,,+RB41
+RB41,UM,1004,123456
$
$     KINEMATIC MOUNT:  SECONDARY MIRROR
$
RBE1,1002,910,123,1112,23,40,3,,+RB21
+RB21,UM,1002,123456
$
$      RIGID EQUIPMENT SECTION
$
RBE2    141     44      123456  42      43      45      46      47
$
$   NODE POINT LOCATIONS
$     NODE#               X (M)    Y (M)    Z (M)
$
GRID    1                 -7.0     0.0      0.0
GRID    2                 -4.0     5.0      0.0
GRID    3                 -4.0     -5.0     0.0
GRID    4                 0.0      5.0      0.0
GRID    5                 4.0      5.0      0.0
GRID    6                 4.0      -5.0     0.0
GRID    7                 7.0      0.0      0.0
GRID    8                 -7.0     0.0      2.0
GRID    9                 -4.0     5.0      2.0
GRID    1004              0.0      4.0      2.0
GRID    10                -4.0     -5.0     2.0
GRID    11                4.0      5.0      2.0
GRID    12                4.0      -5.0     2.0
```

```
GRID    910             -4.0    -2.5    2.0
GRID    1112            4.0     -2.5    2.0
GRID    13              7.0     0.0     2.0
GRID    14              -6.0    0.0     12.
GRID    15              -4.0    4.0     12.
GRID    16              -4.0    -4.0    12.
GRID    17              4.0     4.0     12.
GRID    18              4.0     -4.0    12.
GRID    19              6.0     0.0     12.0
GRID    26              -5.0    0.0     22.0
GRID    27              -4.0    3.0     22.0
GRID    28              -4.0    -3.0    22.0
GRID    2830            0.0     -3.0    22.0
GRID    1001            0.0     -6.5    22.0
GRID    29              4.0     3.0     22.0
GRID    30              4.0     -3.0    22.0
GRID    31              5.0     0.0     22.0
GRID    32              -4.0    10.0    22.0
GRID    3233            0.0     10.0    22.0
GRID    1003            0.0     6.5     22.0
GRID    33              4.0     10.0    22.0
GRID    34              -4.0    -10.0   22.0
GRID    35              4.0     -10.0   22.0
GRID    36              -4.0    3.0     24.0
GRID    37              -4.0    -3.0    24.0
GRID    38              4.0     3.0     24.0
GRID    39              4.0     -3.0    24.0
GRID    40              0.0     2.5     2.0
GRID    1002            0.0     0.0     2.0
GRID    42              0.0     5.0     -0.3
GRID    43              -2.0    0.0     -1.3
GRID    44              0.0     -1.667  -1.3
GRID    45              2.0     0.0     -1.3
GRID    46              -4.0    -5.0    -0.3
GRID    47              4.0     -5.0    -0.3
GRID    48              -26.0   0.0     -1.3
GRID    49              -21.00  0.0     -1.3
GRID    50              -16.0   0.0     -1.3
GRID    51              -11.0   0.0     -1.3
GRID    52              -6.0    0.0     -1.3
GRID    53              6.0     0.0     -1.3
GRID    54              11.0    0.0     -1.3
GRID    55              16.0    0.0     -1.3
GRID    56              21.00   0.0     -1.3
GRID    57              26.0    0.0     -1.3
GRID    100             0.0     0.0     0.0             456
$
$    ELEMENT CONNECTION DATA
$
$     ELEM#   PROP#   NODE    NODE    LOCAL AXIS ORIENTATION VECTOR
$                     A       B
$
BAROR                                 1.0     0.0     0.0     1
CBAR    1       1       1       2
CBAR    2       2       1       3
CBAR    3       3       2       3
CBAR    4       4       2       4     0.0     1.0     0.0     1
```

CBAR	5	5	3	4				
CBAR	6	6	4	5	0.0	1.0	0.0	1
CBAR	7	7	4	6				
CBAR	8	8	3	6	0.0	1.0	0.0	1
CBAR	9	9	5	6				
CBAR	10	10	5	7				
CBAR	11	11	6	7				
CBAR	12	12	1	8				
CBAR	13	13	2	9				
CBAR	14	14	3	10				
CBAR	15	15	5	11				
CBAR	16	16	6	12				
CBAR	17	17	7	13				
CBAR	18	18	3	8				
CBAR	19	19	2	8				
CBAR	21	21	4	9				
CBAR	22	22	4	11				
CBAR	24	24	5	13				
CBAR	25	25	6	13				
CBAR	26	26	1112	3				
CBAR	27	27	6	10				
CBAR	30	30	8	9				
CBAR	31	31	8	10				
CBAR	32	32	9	910				
CBAR	232	232	910	10				
CBAR	33	33	9	40				
CBAR	34	34	910	40				
CBAR	35	35	11	40				
CBAR	36	36	1112	40				
CBAR	37	37	9	11	0.0	1.0	0.0	1
CBAR	38	38	10	12	0.0	1.0	0.0	1
CBAR	39	39	11	1112				
CBAR	239	239	1112	12				
CBAR	201	201	910	1112	0.0	1.0	0.0	1
CBAR	202	202	2	910				
CBAR	203	203	3	910				
CBAR	204	204	5	1112				
CBAR	205	205	6	1112				
CBAR	207	207	12	910				
CBAR	40	40	11	13				
CBAR	41	41	12	13				
CBAR	42	42	14	15				
CBAR	43	43	14	16				
CBAR	44	44	16	15				
CBAR	45	45	17	18				
CBAR	46	46	17	19				
CBAR	47	47	18	19				
CBAR	54	54	26	27				
CBAR	55	55	26	28				
CBAR	56	56	27	28				
CBAR	57	57	29	30				
CBAR	58	58	29	31				
CBAR	59	59	30	31				
CBAR	60	60	27	29	0.0	1.0	0.0	1
CBAR	61	61	27	30				
CBAR	62	62	28	2830	0.0	1.0	0.0	1
CBAR	184	184	2830	30	0.0	1.0	0.0	1

CBAR	63	63	27	36				
CBAR	64	64	28	37				
CBAR	65	65	30	39				
CBAR	66	66	29	38				
CBAR	67	67	29	36				
CBAR	68	68	27	37				
CBAR	69	69	28	39				
CBAR	70	70	30	38				
CBAR	71	71	36	37				
CBAR	72	72	37	39	0.0	1.0	0.0	1
CBAR	73	73	39	38				
CBAR	74	74	36	38	0.0	1.0	0.0	1
CBAR	75	75	37	38				
CBAR	127	127	26	37				
CBAR	128	128	26	36				
CBAR	129	129	31	39				
CBAR	130	130	31	38				
CBAR	76	76	8	14				
CBAR	77	77	10	14				
CBAR	78	78	10	16				
CBAR	79	79	16	9				
CBAR	80	80	9	15				
CBAR	181	181	8	15				
CBAR	182	182	6	40				
CBAR	183	183	2	40				
CBAR	186	186	3	40				
CBAR	187	187	5	40				
CBAR	81	81	11	17				
CBAR	82	82	11	18				
CBAR	83	83	12	18				
CBAR	84	84	12	19				
CBAR	85	85	13	19				
CBAR	86	86	13	17				
CBAR	87	87	14	26				
CBAR	88	88	14	28				
CBAR	89	89	16	28				
CBAR	90	90	16	27				
CBAR	91	91	15	27				
CBAR	92	92	15	26				
CBAR	93	93	17	29				
CBAR	94	94	18	29				
CBAR	95	95	18	30				
CBAR	96	96	19	30				
CBAR	97	97	19	31				
CBAR	98	98	17	31				
CBAR	99	99	15	32				
CBAR	100	100	16	34				
CBAR	101	101	17	33				
CBAR	102	102	18	35				
CBAR	111	111	26	32				
CBAR	112	112	27	32				
CBAR	113	113	27	33				
CBAR	114	114	29	33				
CBAR	115	115	31	33				
CBAR	116	116	32	3233	0.0	1.0	0.0	1
CBAR	185	185	3233	33	0.0	1.0	0.0	1
CBAR	117	117	26	34				

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CBAR     118      118      28      34
CBAR     119      119      30      34
CBAR     120      120      30      35
CBAR     121      121      31      35
CBAR     122      122      34      35      0.0      1.0      0.0      1
CBAR     123      123      32      36
CBAR     124      124      33      38
CBAR     125      125      34      37
CBAR     126      126      35      39
CBAR     131      131      48      49      0.0      1.0      0.0      1
CBAR     132      132      49      50      0.0      1.0      0.0      1
CBAR     133      133      50      51      0.0      1.0      0.0      1
CBAR     134      134      51      52      0.0      1.0      0.0      1
CBAR     135      135      52      43      0.0      1.0      0.0      1
CBAR     136      136      45      53      0.0      1.0      0.0      1
CBAR     137      137      53      54      0.0      1.0      0.0      1
CBAR     138      138      54      55      0.0      1.0      0.0      1
CBAR     139      139      55      56      0.0      1.0      0.0      1
CBAR     140      140      56      57      0.0      1.0      0.0      1
$
$     ISOLATOR SPRINGS
$
$        ELEM#        K      NODE     DOF     NODE     DOF
$                   (N/M)    A        A       B        B
$
CELAS2  142     5.79E3  4        1        42       1
CELAS2  143     5.79E3  4        2        42       2
CELAS2  144     5.79E3  4        3        42       3
CELAS2  145     5.79E3  3        1        46       1
CELAS2  146     5.79E3  3        2        46       2
CELAS2  147     5.79E3  3        3        46       3
CELAS2  148     5.79E3  6        1        47       1
CELAS2  149     5.79E3  6        2        47       2
CELAS2  150     5.79E3  6        3        47       3
$
$      MATERIAL PROPERTY DATA
$
$      MAT#       E                NU       RHO
$
MAT1     100     1.24E+11          0.3      1720.
MAT1     200     1.24E+11          0.3      1720.
MAT1     300     1.24E+11          0.3      2579.70
$
$      LUMPED MASS DATA
$
$CONM2   ELEM#   NODE#             MASS                                 +XXXX
$+XXXX    IXX             IYY                         IZZ
$
$       MIRRORS
$
CONM2    1001    1001              1000.                                +1001
+1001    4083.33          5333.33                     9416.67
CONM2    1002    1002              800.                                 +4040
+4040    1666.67          4266.67                     5933.33
CONM2    1003    1003              1200.                                +1003
+1003    4900.            6400.                       11300.
CONM2    1004    1004              600.                                 +1004
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+1004   200.            800.                    1000.
$
$       EQUIPMENT SECTION
$
CONM2   544     44              3500.                                   +544
+544    20611.          10500.                  28777.
$
$     SOLAR PANELS
$
CONM2   548     48              81.91                                   +548
+548    270.0
CONM2   550     50              163.82                                  +550
+550    540.0
CONM2   552     52              73.82                                   +552
+552    270.0
CONM2   553     53              73.82                                   +553
+553    270.0
CONM2   557     57              81.91                                   +557
+555    540.0
CONM2   555     55              163.82                                  +555
+557    270.0
$
$       ADDITIONAL NON-STRUCTURAL MASS AT MIRROR SUPPORTS
$
CONM2   501     27              69.5
CONM2   502     28              6.74
CONM2   503     29              69.5
CONM2   504     30              6.74
CONM2   505     32              6.74
CONM2   506     33              6.74
CONM2   507     34              69.5
CONM2   508     35              69.5
CONM2   509     9               67.4
CONM2   510     10              67.4
CONM2   511     11              67.4
CONM2   512     12              67.4
$
$       BEAM SECTION PROPERTIES
$
$PBAR                PROP#  MAT#                   AREA             I11      *XXXXXXX
$*XXXXXXX          I22              J
$
PBAR*                   1   100              0.678583E-04     0.439721E-07*       1
*       1    0.439721E-07     0.879442E-07
PBAR*                   2   100              0.678583E-04     0.439721E-07*       2
*       2    0.439721E-07     0.879442E-07
PBAR*                   3   100              0.255098E-03     0.621422E-06*       3
*       3    0.621422E-06     0.124284E-05
PBAR*                   4   100              0.678583E-04     0.439721E-07*       4
*       4    0.439721E-07     0.879443E-07
PBAR*                   5   100              0.343532E-03     0.112695E-05*       5
*       5    0.112695E-05     0.225391E-05
PBAR*                   6   100              0.678583E-04     0.439721E-07*       6
*       6    0.439721E-07     0.879443E-07
PBAR*                   7   100              0.343532E-03     0.112695E-05*       7
*       7    0.112695E-05     0.225391E-05
PBAR*                   8   100              0.104152E-03     0.103587E-06*       8
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*      8   0.103587E-06   0.207174E-06
PBAR*                 9   100            0.255098E-03   0.621422E-06*    9
*      9   0.621422E-06   0.124284E-05
PBAR*                10   100            0.678583E-04   0.439721E-07*   10
*     10   0.439721E-07   0.879442E-07
PBAR*                11   100            0.678583E-04   0.439721E-07*   11
*     11   0.439721E-07   0.879442E-07
PBAR*                12   100            0.678583E-04   0.439721E-07*   12
*     12   0.439721E-07   0.879443E-07
PBAR*                13   100            0.678583E-04   0.439721E-07*   13
*     13   0.439721E-07   0.879443E-07
PBAR*                14   100            0.678583E-04   0.439721E-07*   14
*     14   0.439721E-07   0.879443E-07
PBAR*                15   100            0.678583E-04   0.439721E-07*   15
*     15   0.439721E-07   0.879443E-07
PBAR*                16   100            0.678583E-04   0.439721E-07*   16
*     16   0.439721E-07   0.879443E-07
PBAR*                17   100            0.678583E-04   0.439721E-07*   17
*     17   0.439721E-07   0.879442E-07
PBAR*                18   100            0.678583E-04   0.439721E-07*   18
*     18   0.439721E-07   0.879442E-07
PBAR*                19   100            0.678583E-04   0.439721E-07*   19
*     19   0.439721E-07   0.879442E-07
PBAR*                21   100            0.678583E-04   0.439721E-07*   21
*     21   0.439721E-07   0.879443E-07
PBAR*                22   100            0.678583E-04   0.439721E-07*   22
*     22   0.439721E-07   0.879443E-07
PBAR*                24   100            0.678583E-04   0.439721E-07*   24
*     24   0.439721E-07   0.879442E-07
PBAR*                25   100            0.678583E-04   0.439721E-07*   25
*     25   0.439721E-07   0.879442E-07
PBAR*                26   100            0.140494E-03   0.188490E-06*   26
*     26   0.188490E-06   0.376979E-06
PBAR*                27   100            0.140494E-03   0.188490E-06*   27
*     27   0.188490E-06   0.376979E-06
PBAR*                30   100            0.678583E-04   0.439721E-07*   30
*     30   0.439721E-07   0.879442E-07
PBAR*                31   100            0.678583E-04   0.439721E-07*   31
*     31   0.439721E-07   0.879442E-07
PBAR*                32   100            0.804583E-04   0.618177E-07*   32
*     32   0.618177E-07   0.123635E-06
PBAR*                33   100            0.678583E-04   0.439721E-07*   33
*     33   0.439721E-07   0.879443E-07
PBAR*                34   100            0.678583E-04   0.439721E-07*   34
*     34   0.439721E-07   0.879443E-07
PBAR*                35   100            0.678583E-04   0.439721E-07*   35
*     35   0.439721E-07   0.879443E-07
PBAR*                36   100            0.678583E-04   0.439721E-07*   36
*     36   0.439721E-07   0.879443E-07
PBAR*                37   100            0.104152E-03   0.103587E-06*   37
*     37   0.103587E-06   0.207174E-06
PBAR*                38   100            0.104152E-03   0.103587E-06*   38
*     38   0.103587E-06   0.207174E-06
PBAR*                39   100            0.804583E-04   0.618177E-07*   39
*     39   0.618177E-07   0.123635E-06
PBAR*                40   100            0.678583E-04   0.439721E-07*   40
*     40   0.439721E-07   0.879442E-07
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PBAR*                 41      100             0.678583E-04    0.439721E-07*      41
*     41    0.439721E-07    0.879442E-07
PBAR*                 42      100             0.678583E-04    0.439721E-07*      42
*     42    0.439721E-07    0.879443E-07
PBAR*                 43      100             0.678583E-04    0.439721E-07*      43
*     43    0.439721E-07    0.879443E-07
PBAR*                 44      100             0.104152E-03    0.103587E-06*      44
*     44    0.103587E-06    0.207174E-06
PBAR*                 45      100             0.104152E-03    0.103587E-06*      45
*     45    0.103587E-06    0.207174E-06
PBAR*                 46      100             0.678583E-04    0.439721E-07*      46
*     46    0.439721E-07    0.879443E-07
PBAR*                 47      100             0.678583E-04    0.439721E-07*      47
*     47    0.439721E-07    0.879443E-07
PBAR*                 54      100             0.678583E-04    0.439721E-07*      54
*     54    0.439721E-07    0.879442E-07
PBAR*                 55      100             0.678583E-04    0.439721E-07*      55
*     55    0.439721E-07    0.879442E-07
PBAR*                 56      100             0.678583E-04    0.439721E-07*      56
*     56    0.439721E-07    0.879442E-07
PBAR*                 57      100             0.678583E-04    0.439721E-07*      57
*     57    0.439721E-07    0.879442E-07
PBAR*                 58      100             0.678583E-04    0.439721E-07*      58
*     58    0.439721E-07    0.879442E-07
PBAR*                 59      100             0.678583E-04    0.439721E-07*      59
*     59    0.439721E-07    0.879442E-07
PBAR*                 60      100             0.104152E-03    0.103587E-06*      60
*     60    0.103587E-06    0.207174E-06
PBAR*                 61      100             0.255098E-03    0.621422E-06*      61
*     61    0.621422E-06    0.124284E-05
PBAR*                 62      300             0.0060821       0.0015205    *     62
*     62    0.0015205       0.0030410
PBAR*                 63      100             0.678583E-04    0.439721E-07*      63
*     63    0.439721E-07    0.879443E-07
PBAR*                 64      100             0.678583E-04    0.439721E-07*      64
*     64    0.439721E-07    0.879443E-07
PBAR*                 65      100             0.678583E-04    0.439721E-07*      65
*     65    0.439721E-07    0.879443E-07
PBAR*                 66      100             0.678583E-04    0.439721E-07*      66
*     66    0.439721E-07    0.879443E-07
PBAR*                 67      100             0.117640E-03    0.132154E-06*      67
*     67    0.132154E-06    0.264308E-06
PBAR*                 68      100             0.678583E-04    0.439721E-07*      68
*     68    0.439721E-07    0.879442E-07
PBAR*                 69      100             0.117640E-03    0.132154E-06*      69
*     69    0.132154E-06    0.264308E-06
PBAR*                 70      100             0.678583E-04    0.439721E-07*      70
*     70    0.439721E-07    0.879442E-07
PBAR*                 71      100             0.678583E-04    0.439721E-07*      71
*     71    0.439721E-07    0.879442E-07
PBAR*                 72      100             0.104152E-03    0.103587E-06*      72
*     72    0.103587E-06    0.207174E-06
PBAR*                 73      100             0.678583E-04    0.439721E-07*      73
*     73    0.439721E-07    0.879442E-07
PBAR*                 74      100             0.104152E-03    0.103587E-06*      74
*     74    0.103587E-06    0.207174E-06
PBAR*                 75      100             0.255098E-03    0.621422E-06*      75
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*     75    0.621422E-06    0.124284E-05
PBAR*                 76    100            0.259503E-03    0.643065E-06*    76
*     76    0.643065E-06    0.128613E-05
PBAR*                 77    100            0.424114E-03    0.171765E-05*    77
*     77    0.171765E-05    0.343531E-05
PBAR*                 78    100            0.259503E-03    0.643065E-06*    78
*     78    0.643065E-06    0.128613E-05
PBAR*                 79    100            0.833904E-03    0.664055E-05*    79
*     79    0.664055E-05    0.132811E-04
PBAR*                 80    100            0.259503E-03    0.643065E-06*    80
*     80    0.643065E-06    0.128613E-05
PBAR*                 81    100            0.259503E-03    0.643065E-06*    81
*     81    0.643065E-06    0.128613E-05
PBAR*                 82    100            0.833904E-03    0.664055E-05*    82
*     82    0.664055E-05    0.132811E-04
PBAR*                 83    100            0.259503E-03    0.643065E-06*    83
*     83    0.643065E-06    0.128613E-05
PBAR*                 84    100            0.424114E-03    0.171765E-05*    84
*     84    0.171765E-05    0.343531E-05
PBAR*                 85    100            0.259503E-03    0.643065E-06*    85
*     85    0.643065E-06    0.128613E-05
PBAR*                 86    100            0.398135E-03    0.151367E-05*    86
*     86    0.151367E-05    0.302735E-05
PBAR*                 87    100            0.259503E-03    0.643065E-06*    87
*     87    0.643065E-06    0.128613E-05
PBAR*                 88    100            0.325124E-03    0.100942E-05*    88
*     88    0.100942E-05    0.201883E-05
PBAR*                 89    100            0.259503E-03    0.643065E-06*    89
*     89    0.643065E-06    0.128613E-05
PBAR*                 90    100            0.566323E-03    0.306267E-05*    90
*     90    0.306267E-05    0.612533E-05
PBAR*                 91    100            0.259503E-03    0.643065E-06*    91
*     91    0.643065E-06    0.128613E-05
PBAR*                 92    100            0.348640E-03    0.116072E-05*    92
*     92    0.116072E-05    0.232143E-05
PBAR*                 93    100            0.259503E-03    0.643065E-06*    93
*     93    0.643065E-06    0.128613E-05
PBAR*                 94    100            0.566323E-03    0.306267E-05*    94
*     94    0.306267E-05    0.612533E-05
PBAR*                 95    100            0.259503E-03    0.643065E-06*    95
*     95    0.643065E-06    0.128613E-05
PBAR*                 96    100            0.325124E-03    0.100942E-05*    96
*     96    0.100942E-05    0.201883E-05
PBAR*                 97    100            0.259503E-03    0.643065E-06*    97
*     97    0.643065E-06    0.128613E-05
PBAR*                 98    100            0.348640E-03    0.116072E-05*    98
*     98    0.116072E-05    0.232143E-05
PBAR*                 99    100            0.470559E-03    0.211446E-05*    99
*     99    0.211446E-05    0.422892E-05
PBAR*                100    100            0.470559E-03    0.211446E-05*   100
*    100    0.211446E-05    0.422892E-05
PBAR*                101    100            0.470559E-03    0.211446E-05*   101
*    101    0.211446E-05    0.422892E-05
PBAR*                102    100            0.470559E-03    0.211446E-05*   102
*    102    0.211446E-05    0.422892E-05
PBAR*                111    100            0.259503E-03    0.643065E-06*   111
*    111    0.643065E-06    0.128613E-05
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PBAR*                 112     100             0.678583E-04    0.439721E-07*   112
*     112     0.439721E-07    0.879443E-07
PBAR*                 113     100             0.325124E-03    0.100942E-05*   113
*     113     0.100942E-05    0.201883E-05
PBAR*                 114     100             0.678583E-04    0.439721E-07*   114
*     114     0.439721E-07    0.879443E-07
PBAR*                 115     100             0.259503E-03    0.643065E-06*   115
*     115     0.643065E-06    0.128613E-05
PBAR*                 116     300             0.0060821       0.0015205    *  116
*     116     0.0015205       0.0030410
PBAR*                 117     100             0.259503E-03    0.643065E-06*   117
*     117     0.643065E-06    0.128613E-05
PBAR*                 118     100             0.678583E-04    0.439721E-07*   118
*     118     0.439721E-07    0.879443E-07
PBAR*                 119     100             0.325124E-03    0.100942E-05*   119
*     119     0.100942E-05    0.201883E-05
PBAR*                 120     100             0.678583E-04    0.439721E-07*   120
*     120     0.439721E-07    0.879443E-07
PBAR*                 121     100             0.259503E-03    0.643065E-06*   121
*     121     0.643065E-06    0.128613E-05
PBAR*                 122     100             0.104152E-03    0.103587E-06*   122
*     122     0.103587E-06    0.207174E-06
PBAR*                 123     100             0.716806E-04    0.490653E-07*   123
*     123     0.490653E-07    0.981305E-07
PBAR*                 124     100             0.716806E-04    0.490653E-07*   124
*     124     0.490653E-07    0.981305E-07
PBAR*                 125     100             0.716806E-04    0.490653E-07*   125
*     125     0.490653E-07    0.981305E-07
PBAR*                 126     100             0.716806E-04    0.490653E-07*   126
*     126     0.490653E-07    0.981305E-07
PBAR*                 127     100             0.678583E-04    0.439721E-07*   127
*     127     0.439721E-07    0.879443E-07
PBAR*                 128     100             0.678583E-04    0.439721E-07*   128
*     128     0.439721E-07    0.879443E-07
PBAR*                 129     100             0.678583E-04    0.439721E-07*   129
*     129     0.439721E-07    0.879443E-07
PBAR*                 130     100             0.678583E-04    0.439721E-07*   130
*     130     0.439721E-07    0.879443E-07
PBAR*                 131     100             6.107256E-04    3.561752E-06*   131
*     131     3.561752E-06    7.123504E-06
PBAR*                 132     100             6.107256E-04    3.561752E-06*   132
*     132     3.561752E-06    7.123504E-06
PBAR*                 133     100             6.107256E-04    3.561752E-06*   133
*     133     3.561752E-06    7.123504E-06
PBAR*                 134     100             6.107256E-04    3.561752E-06*   134
*     134     3.561752E-06    7.123504E-06
PBAR*                 135     100             6.107256E-04    3.561752E-06*   135
*     135     3.561752E-06    7.123504E-06
PBAR*                 136     100             6.107256E-04    3.561752E-06*   136
*     136     3.561752E-06    7.123504E-06
PBAR*                 137     100             6.107256E-04    3.561752E-06*   137
*     137     3.561752E-06    7.123504E-06
PBAR*                 138     100             6.107256E-04    3.561752E-06*   138
*     138     3.561752E-06    7.123504E-06
PBAR*                 139     100             6.107256E-04    3.561752E-06*   139
*     139     3.561752E-06    7.123504E-06
PBAR*                 140     100             6.107256E-04    3.561752E-06*   140
```

```
*    140    3.561752E-06    7.123504E-06
PBAR*                181    100                 0.398135E-03    0.151367E-05*    181
*    181    0.151367E-05    0.302735E-05
PBAR*                182    100                 0.343532E-03    0.112695E-05*    182
*    182    0.112695E-05    0.225391E-05
PBAR*                183    100                 0.343532E-03    0.112695E-05*    183
*    183    0.112695E-05    0.225391E-05
PBAR*                184    300                 0.0060821       0.0015205    *   184
*    184    0.0015205       0.0030410
PBAR*                185    300                 0.0060821       0.0015205    *   185
*    185    0.0015205       0.0030410
PBAR*                186    100                 0.343532E-03    0.112695E-05*    186
*    186    0.112695E-05    0.225391E-05
PBAR*                187    100                 0.343532E-03    0.112695E-05*    187
*    187    0.112695E-05    0.225391E-05
PBAR*                201    100                 0.104620E-03    0.104520E-06*    201
*    201    0.104520E-06    0.209040E-06
PBAR*                202    100                 0.923628E-04    0.814640E-07*    202
*    202    0.814640E-07    0.162928E-06
PBAR*                203    100                 0.678583E-04    0.439721E-07*    203
*    203    0.439721E-07    0.879442E-07
PBAR*                204    100                 0.923628E-04    0.814640E-07*    204
*    204    0.814640E-07    0.162928E-06
PBAR*                205    100                 0.678583E-04    0.439721E-07*    205
*    205    0.439721E-07    0.879442E-07
PBAR*                207    100                 0.140494E-03    0.188490E-06*    207
*    207    0.188490E-06    0.376979E-06
PBAR*                232    100                 0.678583E-04    0.439721E-07*    232
*    232    0.439721E-07    0.879442E-07
PBAR*                239100                     0.678583E-04    0.439721E-07*    239
*    239    0.439721E-07    0.879442E-07
$
$      MULTI-POINT CONSTRAINT EQUATION FOR X-AXIS LOS ERROR (NODE 100 DOF 1)
$
MPC*     100                           100               1           -1.0*1000000
*1000000              34                 2  -0.01855287570               *1000001
*1000001                                34               3  -0.14285714286*1000002
*1000002              35                 2  -0.0185528757                *1000003
*1000003                                35               3  -0.14285714286*1000004
*1000004            2830                 3   0.28571428572               *1000005
*1000005                                30               3   0.0          *1000006
*1000006              27                 2   0.08065681999               *1000007
*1000007                                27               3  -0.35489000795*1000008
*1000008              29                 2   0.08065681999               *1000009
*1000009                                29               3  -0.35489000795*1000010
*1000010            3233                 3   0.70978001590               *1000011
*1000011                                33               3   0.0          *1000012
*1000012            1002                 4  -3.48423005566               *1000013
*1000013                                11               2  -0.06210394429*1000014
*1000014               9                 2  -0.06210394429
$
$      MULTI-POINT CONSTRAINT EQUATION FOR Y-AXIS LOS ERROR (NODE 100 DOF 2)
$
MPC*     100                           100               2           -1.0*2000000
*2000000              34                 1  -0.03710575139               *2000001
*2000001                                34               2  -0.04638218924*2000002
*2000002              34                 3  -0.2500000000                *2000003
```

```
*2000003                              35                       2   0.04638218924*2000004
*2000004            35                 3   0.2500000000              *2000005
*2000005                              27                       1   0.16131363998*2000006
*2000006            27                 2  -0.06049261499              *2000007
*2000007                              27                       3  -0.62105751391*2000008
*2000008            29                 2   0.06049261499              *2000009
*2000009                              29                       3   0.62105751391*2000010
*2000010          1002                 5   3.48423005566              *2000011
*2000011                              11                       1  -0.12420788859*2000012
*2000012            11                 2  -0.07762993037              *2000013
*2000013                               9                       2   0.07762993037*2000014
*2000014
$
$      MULTI-POINT CONSTRAINT EQUATION FOR DEFOCUS (NODE 100 DOF 3)
$
MPC*    100                          100                       3            -1.0*3000000
*3000000            34                 3  -0.01912393776              *3000001
*3000001                              35                       3  -0.01912393776*3000002
*3000002          2830                 3   0.12749291836              *3000003
*3000003                              30                       3   0.0          *3000004
*3000004            27                 3   0.77803217347              *3000005
*3000005                              29                       3   0.77803217347*3000006
*3000006          3233                 3  -0.46681930408              *3000007
*3000007                            1002                       3  -0.17849008571*3000008
*3000008             9                 3   0.50000000000              *3000009
*3000009                              11                       3   0.50000000000*3000010
*3000010            40                 3  -2.00000000000
$
$      RIGID BODY SUPPORT
$
SUPORT,44,123456
ENDDATA

******** END OF MEMBER REV03      659 RECORDS ********
```

APPENDIX C

```
ID DRAPER,MODEL2
SOL 3
CHKPNT YES
TIME 10
CEND
TITLE =     ACOSS MODEL #2
SUBTITLE = MODIFIED MODEL - REVISION 4
LABEL = VCOSS STIFFNESS MODEL
MPC = 100
METHOD = 600
DISP = ALL
ESE =ALL
BEGIN BULK
PARAM,USETPRT,1
PARAM   GRDPNT  0
EIGR    600     GIV                             200                     +10
+10     MASS
$
$     KINEMATIC MOUNT:  TERTIARY MIRROR
$
RBE1,1003,27,123,29,23,3233,3,,+RB31
+RB31,UM,1003,123456
$
$     KINEMATIC MOUNT:  PRIMARY MIRROR
$
RBE1,1001,34,123,35,23,2830,3,,+RB11
+RB11,UM,1001,123456
$
$     KINEMATIC MOUNT:  FOCAL PLANE
$
RBE1,1004,11,123,9,23,40,3,,+RB41
+RB41,UM,1004,123456
$
$     KINEMATIC MOUNT:  SECONDARY MIRROR
$
RBE1,1002,910,123,1112,23,40,3,,+RB21
+RB21,UM,1002,123456
$
$      RIGID EQUIPMENT SECTION
$
RBE2    141     44      123456  42      43      45      46      47
$
$   NODE POINT LOCATIONS
$     NODE#           X (M)   Y (M)   Z (M)
$
GRID    1                -7.0    0.0     0.0
GRID    2                -4.0    5.0     0.0
GRID    3                -4.0    -5.0    0.0
GRID    4                0.0     5.0     0.0
GRID    5                4.0     5.0     0.0
GRID    6                4.0     -5.0    0.0
GRID    7                7.0     0.0     0.0
GRID    8                -7.0    0.0     2.0
GRID    9                -4.0    5.0     2.0
GRID    1004             0.0     4.0     2.0
GRID    10               -4.0    -5.0    2.0
GRID    910              -4.0    -2.5    2.0
```

```
GRID    1112           4.0     -2.5    2.0
GRID    11             4.0     5.0     2.0
GRID    12             4.0     -5.0    2.0
GRID    13             7.0     0.0     2.0
GRID    14             -6.0    0.0     12.
GRID    15             -4.0    4.0     12.
GRID    16             -4.0    -4.0    12.
GRID    17             4.0     4.0     12.
GRID    18             4.0     -4.0    12.
GRID    19             6.0     0.0     12.0
GRID    26             -5.0    0.0     22.0
GRID    27             -4.0    3.0     22.0
GRID    28             -4.0    -3.0    22.0
GRID    2830           0.0     -3.0    22.0
GRID    1001           0.0     -6.5    22.0
GRID    29             4.0     3.0     22.0
GRID    30             4.0     -3.0    22.0
GRID    31             5.0     0.0     22.0
GRID    32             -4.0    10.0    22.0
GRID    3233           0.0     10.0    22.0
GRID    1003           0.0     6.5     22.0
GRID    33             4.0     10.0    22.0
GRID    34             -4.0    -10.0   22.0
GRID    35             4.0     -10.0   22.0
GRID    36             -4.0    3.0     24.0
GRID    37             -4.0    -3.0    24.0
GRID    38             4.0     3.0     24.0
GRID    39             4.0     -3.0    24.0
GRID    40             0.0     2.5     2.0
GRID    1002           0.0     0.0     2.0
GRID    42             0.0     5.0     -0.3
GRID    43             -2.0    0.0     -1.3
GRID    44             0.0     -1.667  -1.3
GRID    45             2.0     0.0     -1.3
GRID    46             -4.0    -5.0    -0.3
GRID    47             4.0     -5.0    -0.3
GRID    48             -26.0   0.0     -1.3
GRID    49             -21.00  0.0     -1.3
GRID    50             -16.0   0.0     -1.3
GRID    51             -11.0   0.0     -1.3
GRID    52             -6.0    0.0     -1.3
GRID    53             6.0     0.0     -1.3
GRID    54             11.0    0.0     -1.3
GRID    55             16.0    0.0     -1.3
GRID    56             21.00   0.0     -1.3
GRID    57             26.0    0.0     -1.3
GRID    100            0.0     0.0     0.0             456
$
$     ELEMENT CONNECTION DATA
$
$     ELEM#    PROP#    NODE    NODE      LOCAL AXIS ORIENTATION VECTOR
$                        A       B
$
BAROR                                      1.0     0.0     0.0     1
CBAR    1        1        1       2
CBAR    2        2        1       3
CBAR    3        3        2       3
```

CBAR	4	4	2	4	0.0	1.0	0.0	1
CBAR	5	5	3	4				
CBAR	6	6	4	5	0.0	1.0	0.0	1
CBAR	7	7	4	6				
CBAR	8	8	3	6	0.0	1.0	0.0	1
CBAR	9	9	5	6				
CBAR	10	10	5	7				
CBAR	11	11	6	7				
CBAR	12	12	1	8				
CBAR	13	13	2	9				
CBAR	14	14	3	10				
CBAR	15	15	5	11				
CBAR	16	16	6	12				
CBAR	17	17	7	13				
CBAR	18	18	3	8				
CBAR	19	19	2	8				
CBAR	21	21	4	9				
CBAR	22	22	4	11				
CBAR	24	24	5	13				
CBAR	25	25	6	13				
CBAR	26	26	1112	3				
CBAR	27	27	6	10				
CBAR	30	30	8	9				
CBAR	31	31	8	10				
CBAR	32	32	9	910				
CBAR	232	232	910	10				
CBAR	33	33	9	40				
CBAR	34	34	910	40				
CBAR	35	35	11	40				
CBAR	36	36	1112	40				
CBAR	37	37	9	11	0.0	1.0	0.0	1
CBAR	38	38	10	12	0.0	1.0	0.0	1
CBAR	39	39	11	1112				
CBAR	239	239	1112	12				
CBAR	201	201	910	1112	0.0	1.0	0.0	1
CBAR	202	202	2	910				
CBAR	203	203	3	910				
CBAR	204	204	5	1112				
CBAR	205	205	6	1112				
CBAR	207	207	12	910				
CBAR	40	40	11	13				
CBAR	41	41	12	13				
CBAR	42	42	14	15				
CBAR	43	43	14	16				
CBAR	44	44	16	15				
CBAR	45	45	17	18				
CBAR	46	46	17	19				
CBAR	47	47	18	19				
CBAR	54	54	26	27				
CBAR	55	55	26	28				
CBAR	56	56	27	28				
CBAR	57	57	29	30				
CBAR	58	58	29	31				
CBAR	59	59	30	31				
CBAR	60	60	27	29	0.0	1.0	0.0	1
CBAR	61	61	27	30				
CBAR	62	62	28	2830	0.0	1.0	0.0	1

CBAR	184	184	2830	30	0.0	1.0	0.0	1
CBAR	63	63	27	36				
CBAR	64	64	28	37				
CBAR	65	65	30	39				
CBAR	66	66	29	38				
CBAR	67	67	29	36				
CBAR	68	68	27	37				
CBAR	69	69	28	39				
CBAR	70	70	30	38				
CBAR	71	71	36	37				
CBAR	72	72	37	39	0.0	1.0	0.0	1
CBAR	73	73	39	38				
CBAR	74	74	36	38	0.0	1.0	0.0	1
CBAR	75	75	37	38				
CBAR	127	127	26	37				
CBAR	128	128	26	36				
CBAR	129	129	31	39				
CBAR	130	130	31	38				
CBAR	76	76	8	14				
CBAR	77	77	10	14				
CBAR	78	78	10	16				
CBAR	79	79	16	9				
CBAR	80	80	9	15				
CBAR	181	181	8	15				
CBAR	182	182	6	40				
CBAR	183	183	2	40				
CBAR	186	186	3	40				
CBAR	187	187	5	40				
CBAR	81	81	11	17				
CBAR	82	82	11	18				
CBAR	83	83	12	18				
CBAR	84	84	12	19				
CBAR	85	85	13	19				
CBAR	86	86	13	17				
CBAR	87	87	14	26				
CBAR	88	88	14	28				
CBAR	89	89	16	28				
CBAR	90	90	16	27				
CBAR	91	91	15	27				
CBAR	92	92	15	26				
CBAR	93	93	17	29				
CBAR	94	94	18	29				
CBAR	95	95	18	30				
CBAR	96	96	19	30				
CBAR	97	97	19	31				
CBAR	98	98	17	31				
CBAR	99	99	15	32				
CBAR	100	100	16	34				
CBAR	101	101	17	33				
CBAR	102	102	18	35				
CBAR	111	111	26	32				
CBAR	112	112	27	32				
CBAR	113	113	27	33				
CBAR	114	114	29	33				
CBAR	115	115	31	33				
CBAR	116	116	32	3233	0.0	1.0	0.0	1
CBAR	185	185	3233	33	0.0	1.0	0.0	1

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CBAR    117     117     26      34
CBAR    118     118     28      34
CBAR    119     119     30      34
CBAR    120     120     30      35
CBAR    121     121     31      35
CBAR    122     122     34      35      0.0     1.0     0.0     1
CBAR    123     123     32      36
CBAR    124     124     33      38
CBAR    125     125     34      37
CBAR    126     126     35      39
CBAR    131     131     48      49      0.0     1.0     0.0     1
CBAR    132     132     49      50      0.0     1.0     0.0     1
CBAR    133     133     50      51      0.0     1.0     0.0     1
CBAR    134     134     51      52      0.0     1.0     0.0     1
CBAR    135     135     52      43      0.0     1.0     0.0     1
CBAR    136     136     45      53      0.0     1.0     0.0     1
CBAR    137     137     53      54      0.0     1.0     0.0     1
CBAR    138     138     54      55      0.0     1.0     0.0     1
CBAR    139     139     55      56      0.0     1.0     0.0     1
CBAR    140     140     56      57      0.0     1.0     0.0     1
$
$       ISOLATOR SPRINGS
$
$       ELEM#   K       NODE    DOF     NODE    DOF
$               (N/M)   A       A       B       B
$
CELAS2  142     5.79E3  4       1       42      1
CELAS2  143     5.79E3  4       2       42      2
CELAS2  144     5.79E3  4       3       42      3
CELAS2  145     5.79E3  3       1       46      1
CELAS2  146     5.79E3  3       2       46      2
CELAS2  147     5.79E3  3       3       46      3
CELAS2  148     5.79E3  6       1       47      1
CELAS2  149     5.79E3  6       2       47      2
CELAS2  150     5.79E3  6       3       47      3
$
$       MATERIAL PROPERTY DATA
$
$       MAT#    E               NU      RHO
$
MAT1    100     1.24E+11        0.3     1720.
MAT1    200     1.24E+11        0.3     1720.
MAT1    300     1.24E+11        0.3
$
$       LUMPED MASS DATA
$
$CONM2  ELEM#   NODE#           MASS                    +XXXX
$+XXXX  IXX             IYY             IZZ
$
$       MIRRORS
$
CONM2   1001    1001            1000.                   +1001
+1001   4083.33         5333.33         9416.67
$
CONM2   1002    1002            800.                    +4040
+4040   1666.67         4266.67         5933.33
$
```

```
CONM2   1003    1003            1200.                                   +1003
+1003   4900.           6400.                   11300.
$
CONM2   1004    1004            600.                                    +1004
+1004   200.            800.                    1000.
$
$       EQUIPMENT SECTION
$
CONM2   544     44              3500.                                   +544
+544    20611.          10500.                  28777.
$
$     SOLAR PANELS
$
CONM2   548     48              81.91                                   +548
+548    270.0
CONM2   550     50              163.82                                  +550
+550    540.0
CONM2   552     52              73.82                                   +552
+552    270.0
CONM2   553     53              73.82                                   +553
+553    270.0
CONM2   557     57              81.91                                   +557
+555    540.0
CONM2   555     55              163.82                                  +555
+557    270.0
$
$       ADDITIONAL NON-STRUCTURAL MASS AT MIRROR SUPPORTS
$
CONM2   501     27              69.5
CONM2   502     28              6.74
CONM2   503     29              69.5
CONM2   504     30              6.74
CONM2   505     32              6.74
CONM2   506     33              6.74
CONM2   507     34              69.5
CONM2   508     35              69.5
CONM2   509     9               67.4
CONM2   510     10              67.4
CONM2   511     11              67.4
CONM2   512     12              67.4
$
$       BEAM SECTION PROPERTIES
$
$FBAR                   PROP#   MAT#                    AREA            I11     *XXXXXXX
$*XXXXXXX             I22               J
$
PBAR*                           1100            0.275119E-02    0.301163E-04*       1
*       1       0.301163E-04    0.602325E-04
PBAR*                           2100            0.275119E-02    0.301163E-04*       2
*       2       0.301163E-04    0.602325E-04
PBAR*                           3100            0.471826E-02    0.885774E-04*       3
*       3       0.885774E-04    0.177155E-03
PBAR*                           4100            0.188730E-02    0.141724E-04*       4
*       4       0.141724E-04    0.283447E-04
PBAR*                           5100            0.508172E-02    0.102750E-03*       5
*       5       0.102750E-03    0.205499E-03
PBAR*                           6100            0.188730E-02    0.141724E-04*       6
```

```
*     6    0.141724E-04    0.283447E-04
                   7100                    0.508172E-02    0.102750E-03*     7
PBAR*
*     7    0.102750E-03    0.205499E-03
                   8100                    0.377461E-02    0.566895E-04*     8
PBAR*
*     8    0.566895E-04    0.113379E-03
                   9100                    0.471826E-02    0.885774E-04*     9
PBAR*
*     9    0.885774E-04    0.177155E-03
                  10100                    0.275119E-02    0.301163E-04*    10
PBAR*
*    10    0.301163E-04    0.602325E-04
                  11100                    0.275119E-02    0.301163E-04*    11
PBAR*
*    11    0.301163E-04    0.602325E-04
                  12100                    0.943651E-03    0.354309E-05*    12
PBAR*
*    12    0.354309E-05    0.708619E-05
                  13100                    0.943651E-03    0.354309E-05*    13
PBAR*
*    13    0.354309E-05    0.708619E-05
                  14100                    0.943651E-03    0.354309E-05*    14
PBAR*
*    14    0.354309E-05    0.708619E-05
                  15100                    0.943651E-03    0.354309E-05*    15
PBAR*
*    15    0.354309E-05    0.708619E-05
                  16100                    0.943651E-03    0.354309E-05*    16
PBAR*
*    16    0.354309E-05    0.708619E-05
                  17100                    0.943651E-03    0.354309E-05*    17
PBAR*
*    17    0.354309E-05    0.708619E-05
                  18100                    0.290853E-02    0.336594E-04*    18
PBAR*
*    18    0.336594E-04    0.673188E-04
                  19100                    0.290853E-02    0.336594E-04*    19
PBAR*
*    19    0.336594E-04    0.673188E-04
                  21100                    0.211007E-02    0.177155E-04*    21
PBAR*
*    21    0.177155E-04    0.354309E-04
                  22100                    0.211007E-02    0.177155E-04*    22
PBAR*
*    22    0.177155E-04    0.354309E-04
                  24100                    0.290853E-02    0.336594E-04*    24
PBAR*
*    24    0.336594E-04    0.673188E-04
                  25100                    0.290853E-02    0.336594E-04*    25
PBAR*
*    25    0.336594E-04    0.673188E-04
                  26100                    0.406565E-02    0.657686E-04*    26
PBAR*
*    26    0.657686E-04    0.131537E-03
                  27100                    0.389078E-02    0.602326E-04*    27
PBAR*
*    27    0.602326E-04    0.120465E-03
                  30100                    0.275119E-02    0.301163E-04*    30
PBAR*
*    30    0.301163E-04    0.602325E-04
                  31100                    0.275119E-02    0.301163E-04*    31
PBAR*
*    31    0.301163E-04    0.602325E-04
                  32100                    0.353869E-02    0.498248E-04*    32
PBAR*
*    32    0.498248E-04    0.996495E-04
                  33100                    0.222560E-02    0.197085E-04*    33
PBAR*
*    33    0.197085E-04    0.394169E-04
                  34100                    0.302116E-02    0.363167E-04*    34
PBAR*
*    34    0.363167E-04    0.726334E-04
                  35100                    0.222560E-02    0.197085E-04*    35
PBAR*
*    35    0.197085E-04    0.394169E-04
                  36100                    0.302116E-02    0.363167E-04*    36
PBAR*
*    36    0.363167E-04    0.726334E-04
                  37100                    0.377461E-02    0.566895E-04*    37
PBAR*
*    37    0.566895E-04    0.113379E-03
                  38100                    0.377461E-02    0.566895E-04*    38
PBAR*
*    38    0.566895E-04    0.113379E-03
```

```
PBAR*                 39100                    0.353869E-02    0.498248E-04*      39
*      39    0.498248E-04    0.996495E-04
PBAR*                 40100                    0.275119E-02    0.301163E-04*      40
*      40    0.301163E-04    0.602325E-04
PBAR*                 41100                    0.275119E-02    0.301163E-04*      41
*      41    0.301163E-04    0.602325E-04
PBAR*                 42100                    0.211007E-02    0.177155E-04*      42
*      42    0.177155E-04    0.354309E-04
PBAR*                 43100                    0.211007E-02    0.177155E-04*      43
*      43    0.177155E-04    0.354309E-04
PBAR*                 44100                    0.377461E-02    0.566895E-04*      44
*      44    0.566895E-04    0.113379E-03
PBAR*                 45100                    0.377461E-02    0.566895E-04*      45
*      45    0.566895E-04    0.113379E-03
PBAR*                 46100                    0.211007E-02    0.177155E-04*      46
*      46    0.177155E-04    0.354309E-04
PBAR*                 47100                    0.211007E-02    0.177155E-04*      47
*      47    0.177155E-04    0.354309E-04
PBAR*                 54100                    0.149204E-02    0.885772E-05*      54
*      54    0.885772E-05    0.177154E-04
PBAR*                 55100                    0.149204E-02    0.885772E-05*      55
*      55    0.885772E-05    0.177154E-04
PBAR*                 56100                    0.283095E-02    0.318878E-04*      56
*      56    0.318878E-04    0.637757E-04
PBAR*                 57100                    0.283095E-02    0.318878E-04*      57
*      57    0.318878E-04    0.637757E-04
PBAR*                 58100                    0.149204E-02    0.885772E-05*      58
*      58    0.885772E-05    0.177154E-04
PBAR*                 59100                    0.149204E-02    0.885772E-05*      59
*      59    0.885772E-05    0.177154E-04
PBAR*                 60100                    0.377461E-02    0.566895E-04*      60
*      60    0.566895E-04    0.113379E-03
PBAR*                 61100                    0.471826E-02    0.885774E-04*      61
*      61    0.885774E-04    0.177155E-03
PBAR*                 63100                    0.943651E-03    0.354309E-05*      63
*      63    0.354309E-05    0.708619E-05
PBAR*                 64100                    0.943651E-03    0.354309E-05*      64
*      64    0.354309E-05    0.708619E-05
PBAR*                 65100                    0.943651E-03    0.354309E-05*      65
*      65    0.354309E-05    0.708619E-05
PBAR*                 66100                    0.943651E-03    0.354309E-05*      66
*      66    0.354309E-05    0.708619E-05
PBAR*                 67100                    0.389078E-02    0.602326E-04*      67
*      67    0.602326E-04    0.120465E-03
PBAR*                 68100                    0.298409E-02    0.354310E-04*      68
*      68    0.354310E-04    0.708619E-04
PBAR*                 69100                    0.389078E-02    0.602326E-04*      69
*      69    0.602326E-04    0.120465E-03
PBAR*                 70100                    0.298409E-02    0.354310E-04*      70
*      70    0.354310E-04    0.708619E-04
PBAR*                 71100                    0.283095E-02    0.318878E-04*      71
*      71    0.318878E-04    0.637757E-04
PBAR*                 72100                    0.377461E-02    0.566895E-04*      72
*      72    0.566895E-04    0.113379E-03
PBAR*                 73100                    0.283095E-02    0.318878E-04*      73
*      73    0.318878E-04    0.637757E-04
PBAR*                 74100                    0.377461E-02    0.566895E-04*      74
```

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*       74      0.566895E-04    0.113379E-03
PBAR*                  75100                    0.471826E-02    0.885774E-04*   75
*       75      0.885774E-04    0.177155E-03
PBAR*                  76100                    0.474179E-02    0.894631E-04*   76
*       76      0.894631E-04    0.178926E-03
PBAR*                  77100                    0.535890E-02    0.114265E-03*   77
*       77      0.114265E-03    0.228529E-03
PBAR*                  78100                    0.474179E-02    0.894631E-04*   78
*       78      0.894631E-04    0.178926E-03
PBAR*                  79100                    0.634776E-02    0.160325E-03*   79
*       79      0.160325E-03    0.320650E-03
PBAR*                  80100                    0.474179E-02    0.894631E-04*   80
*       80      0.894631E-04    0.178926E-03
PBAR*                  81100                    0.474179E-02    0.894631E-04*   81
*       81      0.894631E-04    0.178926E-03
PBAR*                  82100                    0.634776E-02    0.160325E-03*   82
*       82      0.160325E-03    0.320650E-03
PBAR*                  83100                    0.474179E-02    0.894631E-04*   83
*       83      0.894631E-04    0.178926E-03
PBAR*                  84100                    0.535890E-02    0.114265E-03*   84
*       84      0.114265E-03    0.228529E-03
PBAR*                  85100                    0.474179E-02    0.894631E-04*   85
*       85      0.894631E-04    0.178926E-03
PBAR*                  86100                    0.527517E-02    0.110722E-03*   86
*       86      0.110722E-03    0.221444E-03
PBAR*                  87100                    0.474179E-02    0.894631E-04*   87
*       87      0.894631E-04    0.178926E-03
PBAR*                  88100                    0.501557E-02    0.100092E-03*   88
*       88      0.100092E-03    0.200185E-03
PBAR*                  89100                    0.474179E-02    0.894631E-04*   89
*       89      0.894631E-04    0.178926E-03
PBAR*                  90100                    0.575936E-02    0.131980E-03*   90
*       90      0.131980E-03    0.263960E-03
PBAR*                  91100                    0.474179E-02    0.894631E-04*   91
*       91      0.894631E-04    0.178926E-03
PBAR*                  92100                    0.510358E-02    0.103636E-03*   92
*       92      0.103636E-03    0.207271E-03
PBAR*                  93100                    0.474179E-02    0.894631E-04*   93
*       93      0.894631E-04    0.178926E-03
PBAR*                  94100                    0.575936E-02    0.131980E-03*   94
*       94      0.131980E-03    0.263960E-03
PBAR*                  95100                    0.474179E-02    0.894631E-04*   95
*       95      0.894631E-04    0.178926E-03
PBAR*                  96100                    0.501557E-02    0.100092E-03*   96
*       96      0.100092E-03    0.200185E-03
PBAR*                  97100                    0.474179E-02    0.894631E-04*   97
*       97      0.894631E-04    0.178926E-03
PBAR*                  98100                    0.510358E-02    0.103636E-03*   98
*       98      0.103636E-03    0.207271E-03
PBAR*                  99100                    0.550238E-02    0.120465E-03*   99
*       99      0.120465E-03    0.240930E-03
PBAR*                 100100                    0.550238E-02    0.120465E-03*   100
*      100      0.120465E-03    0.240930E-03
PBAR*                 101100                    0.550238E-02    0.120465E-03*   101
*      101      0.120465E-03    0.240930E-03
PBAR*                 102100                    0.550238E-02    0.120465E-03*   102
*      102      0.120465E-03    0.240930E-03
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PBAR*                 111100                  0.474179E-02   0.894631E-04*   111
*     111    0.894631E-04   0.178926E-03
PBAR*                 112100                  0.330278E-02   0.434029E-04*   112
*     112    0.434029E-04   0.868059E-04
PBAR*                 113100                  0.501557E-02   0.100092E-03*   113
*     113    0.100092E-03   0.200185E-03
PBAR*                 114100                  0.330278E-02   0.434029E-04*   114
*     114    0.434029E-04   0.868059E-04
PBAR*                 115100                  0.474179E-02   0.894631E-04*   115
*     115    0.894631E-04   0.178926E-03
PBAR*                 117100                  0.474179E-02   0.894631E-04*   117
*     117    0.894631E-04   0.178926E-03
PBAR*                 118100                  0.330278E-02   0.434029E-04*   118
*     118    0.434029E-04   0.868059E-04
PBAR*                 119100                  0.501557E-02   0.100092E-03*   119
*     119    0.100092E-03   0.200185E-03
PBAR*                 120100                  0.330278E-02   0.434029E-04*   120
*     120    0.434029E-04   0.868059E-04
PBAR*                 121100                  0.474179E-02   0.894631E-04*   121
*     121    0.894631E-04   0.178926E-03
PBAR*                 122100                  0.377461E-02   0.566895E-04*   122
*     122    0.566895E-04   0.113379E-03
PBAR*                 123100                  0.343494E-02   0.469460E-04*   123
*     123    0.469460E-04   0.938920E-04
PBAR*                 124100                  0.343494E-02   0.469460E-04*   124
*     124    0.469460E-04   0.938920E-04
PBAR*                 125100                  0.343494E-02   0.469460E-04*   125
*     125    0.469460E-04   0.938920E-04
PBAR*                 126100                  0.343494E-02   0.469460E-04*   126
*     126    0.469460E-04   0.938920E-04
PBAR*                 127100                  0.176541E-02   0.124008E-04*   127
*     127    0.124008E-04   0.248016E-04
PBAR*                 128100                  0.176541E-02   0.124008E-04*   128
*     128    0.124008E-04   0.248016E-04
PBAR*                 129100                  0.176541E-02   0.124008E-04*   129
*     129    0.124008E-04   0.248016E-04
PBAR*                 130100                  0.176541E-02   0.124008E-04*   130
*     130    0.124008E-04   0.248016E-04
PBAR*                 181100                  0.527517E-02   0.110722E-03*   181
*     181    0.110722E-03   0.221444E-03
PBAR*                 182100                  0.412004E-02   0.675402E-04*   182
*     182    0.675402E-04   0.135080E-03
PBAR*                 183100                  0.241739E-02   0.232515E-04*   183
*     183    0.232515E-04   0.465031E-04
PBAR*                 186100                  0.412004E-02   0.675402E-04*   186
*     186    0.675402E-04   0.135080E-03
PBAR*                 187100                  0.241739E-02   0.232515E-04*   187
*     187    0.232515E-04   0.465031E-04
PBAR*                 201100                  0.377461E-02   0.566895E-04*   201
*     201    0.566895E-04   0.113379E-03
PBAR*                 202100                  0.366236E-02   0.533679E-04*   202
*     202    0.533679E-04   0.106736E-03
PBAR*                 203100                  0.151058E-02   0.907917E-05*   203
*     203    0.907917E-05   0.181583E-04
PBAR*                 204100                  0.366236E-02   0.533679E-04*   204
*     204    0.533679E-04   0.106736E-03
PBAR*                 205100                  0.151058E-02   0.907917E-05*   205
```

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*     205     0.907917E-05    0.181583E-04
PBAR*                 207100                  0.395462E-02    0.622256E-04*    207
*     207     0.622256E-04    0.124451E-03
PBAR*                 232100                  0.117957E-02    0.553610E-05*    232
*     232     0.553610E-05    0.110722E-04
PBAR*                 239100                  0.117957E-02    0.553610E-05*    239
*     239     0.553610E-05    0.110722E-04
PBAR*                  62300                  0.0060821       0.0015205   *     62
*      62     0.0015205       0.0030410       15.69
PBAR*                 116300                  0.0060821       0.0015205   *    116
*     116     0.0015205       0.0030410       15.69
PBAR*                 184300                  0.0060821       0.0015205   *    184
*     184     0.0015205       0.0030410       15.69
PBAR*                 185300                  0.0060821       0.0015205   *    185
*     185     0.0015205       0.0030410       15.69
PBAR*                 131200                      1.257E-3        3.142E-4     131
*     131         3.142E-4        6.285E-4        3.82
PBAR*                 132200                      1.257E-3        3.142E-4*    132
*     132         3.142E-4        6.285E-4        3.82
PBAR*                 133200                      1.257E-3        3.142E-4*    133
*     133         3.142E-4        6.285E-4        3.82
PBAR*                 134200                      1.257E-3        3.142E-4*    134
*     134         3.142E-4        6.285E-4        3.82
PBAR*                 135200                      1.257E-3        3.142E-4*    135
*     135         3.142E-4        6.285E-4        3.82
PBAR*                 136200                      1.257E-3        3.142E-4*    136
*     136         3.142E-4        6.285E-4        3.82
PBAR*                 137200                      1.257E-3        3.142E-4*    137
*     137         3.142E-4        6.285E-4        3.82
PBAR*                 138200                      1.257E-3        3.142E-4*    138
*     138         3.142E-4        6.285E-4        3.82
PBAR*                 139200                      1.257E-3        3.142E-4*    139
*     139         3.142E-4        6.285E-4        3.82
PBAR*                 140200                      1.257E-3        3.142E-4*    140
*     140         3.142E-4        6.285E-4        3.82
$
$
$
$      MULTI-POINT CONSTRAINT FOR X-AXIS LOS ERROR (NODE 100 DOF 1)
$
MPC*     100                          100               1             -1.0*1000000
*1000000              34                2  -0.01855287570                 *1000001
*1000001                               34               3  -0.14285714286*1000002
*1000002              35                2  -0.0185528757                  *1000003
*1000003                               35               3  -0.14285714286*1000004
*1000004            2830                3   0.28571428572                 *1000005
*1000005                               30               3   0.0           *1000006
*1000006              27                2   0.08065681999                 *1000007
*1000007                               27               3  -0.35489000795*1000008
*1000008              29                2   0.08065681999                 *1000009
*1000009                               29               3  -0.35489000795*1000010
*1000010            3233                3   0.70978001590                 *1000011
*1000011                               33               3   0.0           *1000012
*1000012            1002                4  -3.48423005566                 *1000013
*1000013                               11               2  -0.06210394429*1000014
*1000014               9                2  -0.06210394429
$
```

```
$       MULTI-POINT CONSTRAINT FOR Y-AXIS LOS ERROR (NODE 100 DOF 2)
$
MPC*    100                             100               2            -1.0*2000000
*2000000             34                   1  -0.03710575139                *2000001
*2000001                                 34               2  -0.04638218924*2000002
*2000002             34                   3  -0.2500000000                 *2000003
*2000003                                 35               2   0.04638218924*2000004
*2000004             35                   3   0.2500000000                 *2000005
*2000005                                 27               1   0.16131363998*2000006
*2000006             27                   2  -0.06049261499                *2000007
*2000007                                 27               3  -0.62105751391*2000008
*2000008             29                   2   0.06049261499                *2000009
*2000009                                 29               3   0.62105751391*2000010
*2000010           1002                   5   3.48423005566                *2000011
*2000011                                 11               1  -0.12420788859*2000012
*2000012             11                   2  -0.07762993037                *2000013
*2000013                                  9               2   0.07762993037*2000014
*2000014
$
$       MULTI-POINT CONSTRAINT EQUATION FOR DEFOCUS (NODE 100 DOF 3)
$
MPC*    100                             100               3            -1.0*3000000
*3000000             34                   3  -0.01912393776                *3000001
*3000001                                 35               3  -0.01912393776*3000002
*3000002           2830                   3   0.12749291836                *3000003
*3000003                                 30               3   0.0          *3000004
*3000004             27                   3   0.77803217347                *3000005
*3000005                                 29               3   0.77803217347*3000006
*3000006           3233                   3  -0.46681930408                *3000007
*3000007                               1002               3  -0.17849008571*3000008
*3000008              9                   3   0.50000000000                *3000009
*3000009                                 11               3   0.5000000000*3000010
*3000010             40                   3  -2.00000000000
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